HUMAN-BEAR INTERACTIONS IN THE NORTH SLOPE OILFIELDS OF ALASKA (USA): CHARACTERISTICS OF GRIZZLY BEAR SIGHTINGS AND USE OF INFRARED FOR BEAR DEN DETECTION

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ABSTRACT

Minimizing unsafe human-bear (*Ursus spp.*) interactions in the North Slope oilfields of Alaska (USA) requires knowledge of where they occur and methods to prevent them. My research goals were to characterize the spatial and temporal dynamics of grizzly bear (*U. arctos*) sightings during the non-denning season around industrial infrastructure in the North Slope oilfields over the past 25 years (Chapter 2), and to evaluate the efficacy of forward-looking infrared (FLIR) systems to detect grizzly bears and polar bears (*U. maritimus*) in their winter dens (Chapter 3). I used reports (n = 2,453) of summer grizzly bear sightings collected by oilfield security officers from 1990–2014 to estimate how the spatial distribution of sightings for food-conditioned (FC) and natural food (NF) bears changed following restriction of bear access to anthropogenic food waste (to be known hereafter as "treatment") in 2001. I found that concentrations of FC bear sightings shifted toward the landfill with medium-low effect (Hedges' g = 0.41), one of the only remaining areas with available food waste, after the treatment. The treatment also decreased NF bear sighting distances to landfill with low effect (Hedges' g = 0.15). My findings suggested that grizzly bear access to food waste should be prevented to minimize negative human-bear interactions and that an active bear reporting system facilitates adaptive management of human-bear interactions. During the winter, grizzly bears and pregnant female polar bears enter dens in areas that overlap anthropogenic activity. FLIR techniques have been used to locate occupied dens by detecting heat emitted from denned bears. However, the effects of environmental conditions on den detection have not been rigorously evaluated. I used a FLIR-equipped Unmanned Aircraft System (UAS) to collect images of artificial polar bear (APD) and grizzly bear (AGD) dens from horizontal and vertical perspectives from December 2016 to April 2017 to assess how odds of detection changed relative to den characteristics and environmental conditions. I used logistic regression to estimate effects of 11 weather variables on odds of detection using 291 images. I found that UAS-FLIR detected APDs two times better than AGDs, vertical perspective detected 4 times better than horizontal, and that lower air temperatures and wind speeds, and the absence of precipitation and direct solar radiation increased odds of detection for APDs. An increase of 1°C air temperature lowered the odds of detection by 12% for APD, and 8% for AGDs, but physical den characteristics such as den snow wall thickness determined detectability of AGDs. UAS-FLIR surveys should be conducted on cold, clear days, with calm winds and minimal solar radiation, early in the denning season. UAS-FLIR detection of bear dens can be effective but should be confirmed by a secondary method.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF APPENDICES

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CHAPTER 1: INTRODUCTION

The potential for human-bear (*Ursus spp.*) interactions is dependent on availability of bear habitat, associated bear density, and the extent of human activity in proximity to that habitat (Mattson 1990, Gibeau et al. 2000, Wilson et al. 2005, Wilder et al.2007, Morehouse and Boyce 2017). In regions where bear distribution and human activity overlap, bears can coexist by habituating to human activity and by avoiding human-occupied space (Peek et al. 1987). Managers can lethally remove or relocate bears that no longer exhibit a natural wariness of people if the bears are a perceived or actual threat to life or property (Herrero 1985, Wilder et al. 2007, Bentzen et al. 2014).

The North Slope oilfields of Alaska are unique in that they are in a remote region of arctic bear habitat, with a relatively high density of people working within an expanding industrial complex. At any one time, the oilfields employ between 5,000 and 10,000 personnel spread out across an approximately 1,000 km network of roads and continually operating facilities within historic grizzly bear (*U. arctos*) and polar bear (*U. maritimus*) habitat. This activity has led to negative human-bear interactions such as food conditioning of bears, human-caused bear mortality, and bear den disturbance (Shideler and Hechtel 2000, Bentzen et al. 2014, Wilder et al. 2017). Warming temperatures in the Arctic and the resulting coastal sea ice decline observed over the past 4 decades have led to an increase in polar bear use of terrestrial habitat (Stoeve et al. 2014, Stern and Laidre 2016). Oilfield operators in the region are required to locate and avoid bear dens as a condition of their land lease agreement, but doing so requires a safe and effective method to detect occupied dens.

The goals of this study were to characterize the spatial and temporal dynamics of grizzly bear sightings during the non-denning season around industrial infrastructure in the North Slope oilfields over the past 25 years, and to evaluate the efficacy of using forward-looking infrared

(FLIR) systems to detect grizzly bears and polar bears in their winter dens. The results from this research will help to provide a baseline understanding of human-bear interactions in the oilfields and can be used to enhance bear management strategies designed to minimize negative human-bear interactions in the Arctic.

1.1 Background for Chapter 2: Characteristics of Grizzly Bear Sightings in the North Slope Oilfields, Alaska

Humans have inhabited regions of the Alaska North Slope for thousands of years in relatively low numbers and localized regions (Wilder et al. 2017). The discovery of oil and gas in Prudhoe Bay led to an increase in human activity on the North Slope beginning in the 1970s (Bentzen et al. 2014), and development continues to expand relative to the size of the industrial footprint and the number of on-site workers. Grizzly bears in this region tend to have large individual home ranges, relatively low population densities, and low reproductive rates (Reynolds 1980, Shideler and Hechtel 2000) compared with other North American grizzly bear populations (see Craighead et al. 1995). Expanding oil exploration and development increases the likelihood of human-bear interactions, and the species' low reproductive rate makes the grizzly bear population vulnerable to disturbance (Reynolds 1980).

During the summer months it is common for oilfield personnel to see grizzly bears that occupy home ranges overlapping areas of industrial use (Shideler and Hechtel 2000). Many of these grizzly bears are habituated to oilfield activities, and a subset of the resident bear population is food-conditioned. Food-conditioned bears have learned to associate humans with access to food waste (Bentzen et al. 2014). Food conditioning increases the likelihood that a bear will continue to seek food from people, damage property, threaten human safety, and risk human-caused bear mortality (Herrero 1985, Wilder et al. 2007, Bentzen et al. 2014).

A stipulation in state and federal oil leases requires that oilfield operators collect grizzly bear observations and submit them to the Alaska Department of Fish and Game (ADF&G). Grizzly bear sighting reports are recorded by industry security officers that patrol the North Slope oilfields as part of their duties. These sighting reports span a time frame before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste were implemented. The specific objectives of this evaluation study (Chapter 2) were to (1) assess how human-bear interactions changed before and after a large-scale reduction in food waste, and (2) describe the effect that natural and human-made landscape features have had on reported food-conditioned, natural food, unknown, and unmarked bear sightings. This evaluation study may help explain trends in human-bear interactions and inform bear management in human-controlled landscapes. It builds on existing knowledge of the behavior of grizzly bears in the North Slope oilfields and generally in the Arctic, with implications for bears and other wildlife in expanding industrial landscapes.

1.2 Background for Chapter 3: Use of Forward-Looking Infrared for Bear Den Detection in the Alaska Arctic

Warming temperatures and new resource extraction opportunities in the Arctic have led to a decrease in coastal sea ice and an increase in seasonal human activity, respectively, in remote areas that were difficult to access in the past (Stoeve et al. 2014, Stern and Laidre 2016). The retreat of coastal sea ice has resulted in reduced seal (Phocidae) hunting opportunities for polar bears during their hyperphagic period in late spring and early summer (Ramsay and Stirling 1988), and this increased fasting period has been shown to have negative effects on polar bear body condition and a reduction in long-term survival (Stirling and Derocher 1993, Stirling et al. 1999, Regehr et al. 2007, 2010, Bromaghin et al. 2015). In the Arctic Report Card 2018, Osbourne et al. (2018) reported that the 12 lowest extents of arctic sea ice in the satellite record have occurred in the past 12 years and that the ice is younger and thinner, and covers less area than in the past. The cumulative effects on polar bears of habitat loss, subsequent decline in body condition, increased use of terrestrial habitat, and increasing human activity in the Arctic have the potential to increase the occurrence of negative human-polar bear interactions (Stirling and Derocher 1993, Derocher et al. 2004, Stirling and Parkinson 2006, Towns et al. 2009).

Grizzly bears enter their dens between late September and mid-November and emerge in April or early May. Pregnant female polar bears enter their dens between late November and December, where they will remain until April or early May. Pregnant females give birth while inside their winter dens to protect their young from the harsh outside conditions. Newborn cubs are most vulnerable during this young stage of life, and if the mother is disturbed, it is more likely that her cubs will be abandoned and die if she evacuates the den (Shideler and Hechtel 2000, Amstrup et al. 2004). Changing weather patterns and ice regimes in arctic Alaska are leading more polar bears to select terrestrial den habitat, which increases the chances of adverse human-bear den interactions (Amstrup and Gardner 1994, Olson et al. 1996, Fischbach et al. 2007). To mitigate human-bear den interactions, FLIR cameras have been used to visualize and locate bear dens so that they can be avoided (Amstrup et al. 2004, Shideler and Perham 2013, Robinson et al. 2014). Forward-looking infrared measures *emissivity*, which is the ability of a substance to release thermal energy (e.g., heat; Hyll 2012) and has been used primarily to locate the dens of polar bears (Amstrup et al. 2004, Robinson et al. 2014) and grizzly bears (Shideler 2014) in the oilfield region. However, based on my literature search, a robust evaluation of how FLIR systems are affected by dynamic environmental conditions had not been conducted before this study.

Amstrup et al. (2004) used a FLIR imager mounted on a helicopter to observe dens of radio-collared pregnant female polar bears, and recorded weather conditions to compare detections with non-detections. Robinson et al. (2014) continued to explore the utility of FLIR imagers by evaluating limitations and optimal weather conditions using hand-held FLIR cameras from the ground to conduct routine observations of human-made (artificial) polar bear dens from the horizontal perspective. Shideler and Perham (2013) used FLIR imagers operated from helicopters and fixed-wing aircraft, as well as hand-held FLIR cameras at ground level to evaluate grizzly bear den-detection techniques and develop protocols for managers. Each of these studies revealed limitations in the effectiveness of FLIR systems due to varying environmental factors that caused operational constraints and influenced den detection; however, the studies also highlighted opportunities for improvement. Specifically, studies that collected FLIR images of occupied bear dens were limited by a small sample size with which to model detection probabilities under differing weather conditions, and the physical characteristics of the bear dens were unknown (Amstrup et al. 2004, Shideler and Perham 2013). Also, the collected images of artificial bear dens by Robinson et al. (2014) were from the horizontal perspective, using a hand-held FLIR camera during a 19-day period in March, a period that is unlikely to accurately represent variation in winter weather conditions across the denning season. In an effort to overcome the limitations of previous studies, this winter den detection study (Chapter 3) used FLIR-equipped unmanned aircraft systems (UASs) and artificial grizzly bear and polar bear dens that had known characteristics and locations for routine observation. The specific objective of this study was to collect a sufficient sample of artificial bear den UAS-FLIR imagery across the polar bear den season (December to April) to (1) identify the critical differences in detection of grizzly bear and polar bear dens from horizontal and vertical perspectives, and (2) model the relative influence of environmental variables on the UAS-FLIR camera's ability to detect bear dens. This study aims to benefit multiple stakeholders including oil industry groups, bear managers, and scientists interested in the use of UAS and FLIR cameras for wildlife application in the Arctic by identifying optimal conditions for highest odds of surface heat differential detection. It is my hope that the findings from this study will contribute to conservation by advancing knowledge of a technique that can monitor bear populations during a period of rapid social and ecological change as the Arctic becomes warmer and more accessible for human use.

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CHAPTER 2: CHARACTERISTICS OF GRIZZLY BEAR SIGHTINGS IN THE NORTH SLOPE OILFIELDS, ALASKA[1]

2.1 Abstract

Minimizing unsafe human-bear interactions in the North Slope oilfields of Alaska (USA) requires an understanding of where these interactions occur and how to prevent them. In an Alaska Department of Fish and Game (ADF&G) grizzly bear (*Ursus arctos*) study, oilfield security officers have recorded bear sightings using a Grizzly Bear Sighting and Hazing Report (GBSHR) form since 1990. Out of n = 2,453 GBSHRs, 49% were of radio-collared bears that ADF&G had categorized as food-conditioned or natural-food bears, and 51% were reported as unknown or unmarked bears. Bear access to food waste has been common around oilfield facilities, but between 1999 and 2001, bear-resistant garbage containers were deployed, and an electric fence was constructed around the primary landfill. These measures reduced the availability of food waste around facilities; however, food waste continued to be available at the landfill and in the community of Deadhorse. Using coordinates for sightings, we divided bear categories into before (1990–2000) and after (2001–2014) changes in waste management (hereafter referred to as "treatment") to generate bear distance-to-landscape feature estimates for facilities, roads, rivers, and the landfill. We compared distances between time periods with Hedges' g effect-size estimates and "hot spot" maps to quantify changes in spatial distribution of sightings after treatment. Treatment concentrated FC bear sightings around the landfill with a medium effect (Hedge's g = 0.41). Other bear categories showed minimal changes after treatment, indicating that habituated bears can coexist with humans in industrialized settings with proactive management programs. In conclusion, grizzly bear access to food waste should be

[1]Pedersen, N.J., T.J. Brinkman, R.T. Shideler, S.M. Brainerd, and M.S. Lindberg. 2019. Characteristics of Grizzly Bear Sightings in the North Slope Oilfields, Alaska. Prepared for submission to *Ursus*.

prevented to minimize negative human-bear interactions, and an active reporting system facilitates adaptive management.

2.2 Introduction

Anthropogenic activity in the Arctic has affected the behavioral ecology of resident wildlife populations, including that of the grizzly bear (*Ursus arctos*; Reynolds 1980, Shideler and Hechtel 2000), which reaches the northwestern limit of its range along the coast of the Beaufort Sea, Alaska (USA). Since the early 1970s, extensive petroleum exploration and extraction in the Arctic Coastal Plain region of the Alaska North Slope has created a 1,000 km network of industrial roads and facilities known as the North Slope oilfields (Bentzen et al. 2014). The relatively low-density grizzly bear population that inhabits this region tends to have larger individual home ranges and lower reproductive rates compared with other North American grizzly bear populations (Craighead et al. 1995, Shideler and Hechtel 2000). The great distances that these bears are known to travel increases the likelihood that individual bears will encounter anthropogenic activity at some point during their lives, and their low reproductive rate increases the population's vulnerability to disturbance (Reynolds 1980). Grizzly bears are large predators that can pose a threat to human life and property; therefore, it is important that human-bear interactions are managed with respect to human safety, but with bear conservation considerations as well.

Since oil development began in arctic Alaska, oilfield operators have initiated programs that intended to reduce conflicts with local wildlife populations (Shideler and Hechtel 2000), but the availability of anthropogenic food sources to bears in the form of food waste has led to negative human-bear interactions and the killing of food waste-seeking bears (Milke 1977, Follmann and Hechtel 1990, Bentzen et al. 2014). As part of the lease conditions, oilfield operators are required to collect grizzly bear observations and submit reporting forms to the ADF&G, which developed the Grizzly Bear Sighting and Hazing Report (GBSHR) form (Figure 2.1) for oilfield security officers (SOs) to complete after each bear sighting. The forms are submitted to ADF&G for management decision-making (Shideler and Hechtel 2000). Since 1990 when the form was created, 2,453 GBSHRs have been entered into the database, providing a substantial source of information about oilfield bears, including human-bear interactions, habitat use, temporal-spatial behavior, and response to hazing by SOs (Figure 2.2).

Previous studies on bear reports in rural or remote areas have relied on a public reporting system to track human-bear conflicts. Morehouse and Boyce (2017) collected large carnivore complaint reports submitted by the public in western Alberta and examined spatial distribution and annual temporal behavior to understand conflict patterns, mitigation options, and human factors contributing to reporting rates. Wilson et al. (2005) focused on reported grizzly bear-human conflicts on the east front of the Rocky Mountains in Montana and examined spatial patterns, natural landscape features present, and anthropogenic attractants associated with high-conflict areas. The authors included private and public land in their study area and relied on public reports of sightings, but mostly incidents, as the source of their information. Previous investigations have not relied on a standardized and long-term reporting program that extended beyond negative interactions to include all encounters.

The need for a more standardized reporting system that included multiple types of human-bear encounters led the National Park Service to initiate the Bear-Human Information Management System (BHIMS), a systematic method of collecting and analyzing human-bear interaction data in national parks and monuments. Information included in the BHIMS database came from bear sightings, human-bear interactions (encounters, incidents, and legal harvest of bears within parks), and natural history and management data (Wilder et al. 2007). In a study conducted in national parks in Alaska by Wilder et al. (2007), BHIMS data revealed trends in bear spatial-temporal use that were unexpected and helpful to park managers tasked with identifying and addressing human-bear conflict issues. The BHIMS is especially useful because it allows for comparison among other parks using the same system for observing similarities and differences in human-bear interactions. The study by Wilder et al. (2007), however, was tasked with the duty of integrating a broad spectrum of data that varied in information source and data quality (e.g.,hearsay records as well as law enforcement case incident reports). Though the GBSHR is like the BHIMS and other public reporting systems in many respects, it differs in that it is designed for use by trained reporters in a highly controlled industrial landscape where public access is restricted and a relatively dense network of roads is patrolled at regular intervals. In contrast to public reports that are dependent on an individual's willingness to report and non-systematic interpretation of bear behavior, oilfield SOs responsible for the GBSHR are trained by ADF&G to describe commonly observed bear behavior and to identify marked bears. Also, they are instructed by their employer to prioritize the reporting process in their duties. The GBSHR is part of an ongoing ADF&G oilfield grizzly bear project and contains reports of tagged and radio-collared bears.

Garbage disposal has always been a challenge in the oilfields. There are 5,000 to 10,000 people working in the oilfields and Deadhorse at any one time, and workers are concentrated in different regions depending on the level of work activity taking place and the demand for labor (Bentzen et al. 2014). This human activity in an industrial setting has led to the accumulation of food waste in areas accessible to grizzly bears. As a result of the long-term availability of food waste, in some years as many as 1 out of 3 oilfield bears were food-conditioned (FC); i.e., they exhibit a learned association of humans with available food (Herrero 1985, Mattson et al. 1992, Hopkins et al. 2010). Bears captured, sampled, and radio-collared between 1991 and 2014 by ADF&G as part of its study in the oilfields were classified as FC or natural-food (NF) bears based on observed foraging habits and stable isotope markers. Complete grizzly bear hairs were collected upon each capture, and the δ^{13} N and δ^{13}C content of the hair of each bear was compared with the contents of natural bear foods in the region as well as the stable isotope signatures of humans in the area (Bentzen et al. 2014). Distinctions as to FC and NF bear were verified by aerial and ground-based observations of FC bears feeding on garbage > 3 days per year (see Bentzen et al. 2014 for more detail). The GBSHR also includes reports of unknown (UNK) bears that the reporting SO was unable to distinguish as FC or NF based on ear flag identification markers, and reports of unmarked (UNM) bears that clearly did not have ear flags or a radio-collar.

As a compilation of arctic grizzly bear reports from a long-term monitoring project, this study characterizes the history of human-bear interactions in the North Slope oilfields and helps to inform the challenge of human-bear coexistence in the Arctic and in other managed landscapes around the world. Our goal was to use the data collected from 25 years of GBSHR forms to describe associations among bear foraging behavior, food waste management, and bear sighting locations. More specifically, objectives were (1) to assess how human-bear interactions changed from when food waste was available to bears (1990–2000) to when a large-scale effort was made to reduce bear access to food waste (2001–2014); and (2) to describe reported FC, NF, UNK, and UNM bear sighting distribution in relation to landscape features. We anticipate our study will help explain trends in human-bear interactions and inform bear management in human-controlled landscapes. This study builds on existing knowledge of the behavior of food-conditioned grizzly bears in the Arctic, with implications for bears and other wildlife in other industrial settings.

2.3 Study Area

The North Slope oilfield study area is delineated by the Beaufort Sea coastline to the north, Teshekpuk Lake to the west, the Canning River to the east, and a line approximately 100 km inland to the south (Shideler and Hechtel 2000); however, the road system is concentrated around a central spine road that traverses the oilfields from east to west (Figure 2.3). The industrial area includes approximately 1,000 km of roads that connect six individual oilfields and the unincorporated community of Deadhorse (Bentzen et al. 2014). This network of gravel roads runs parallel to aboveground pipelines that intersect drill pads, processing facilities, storage areas, several hotels and other employee housing, as well as three airports. A 14-ha garbage landfill is located near Deadhorse and is operated by the North Slope Borough (NSB), the local government agency (Shideler and Hechtel 2000).

Deadhorse is located adjacent to the North Slope oilfields, has no permanent residents, and functions as an industrial support enclave for oilfield activity (Bentzen et al. 2014). The community is publicly accessible by the Dalton Highway of Alaska's public road system and by a commercial airport. Public Safety Officers (PSO), the local police employed by the NSB, are stationed on-site and are able to respond to most complaints, including grizzly bear incidents (Shideler and Hechtel 2000). The PSOs do not document bear sightings, and therefore, GBSHR bear sightings were underreported in Deadhorse during our study period. Any GBSHRs made in Deadhorse were because an oilfield SO was present to assist the PSO or encountered a bear while transiting the area. The oilfield road system is always regularly patrolled by oil-company SOs to monitor oilfield activities and maintain a safe and functional workplace (Shideler and

Hechtel 2000, Bentzen et al. 2014). Drill pad operators, facility managers, and maintenance and other oilfield workers that are always present at facilities or on the road system are instructed to report safety issues, including bear sightings, to SOs for monitoring and response purposes. The SOs are trained by ADF&G to haze oilfield bears only if the bear poses a safety hazard to itself or to oilfield activities (Shideler and Hechtel 2000). Hazing is defined as a technique in which deterrents are directed at a bear to immediately modify its undesirable behavior (Schirokauer and Boyd 1998) and includes such actions as vehicle pursuit, honking a vehicle horn and yelling, and the application of painful stimuli such as using non-lethal projectiles (e.g., rubber bullets and bean bags).

Food waste has been made available to bears throughout the history of the North Slope oilfields, primarily in the borough landfill where garbage is dumped, but it has also been distributed throughout the oilfields and in Deadhorse in the form of bear-accessible containers outside of personnel camps, hotels, and other facilities that have kitchen areas and garbage disposal systems holding food waste awaiting transit to the landfill (Bentzen et al. 2014). An FC bear foraging strategy increases the likelihood that it will continue to seek food from people, damage property, and risk human-caused mortality (Herrero 1985, Wilder et al. 2007, Bentzen et al. 2014). The direct feeding of wildlife by employees in the oilfields has always been strongly discouraged, and the direct feeding of grizzly bears has not been observed by project personnel since the inception of the oilfield grizzly bear project (Shideler and Hechtel 2000, Bentzen et al. 2014).

Between the years 1999 and 2001, oil companies completed efforts to restrict bear access to food waste on their leased lands in the oilfield by installing bear-resistant garbage containers on the oil pads and at personnel camps and operation centers. By 2000, the NSB completed construction of an electric fence around the landfill (Bentzen et al. 2014), and although Deadhorse had the same bear-resistant garbage containers by 2001, food waste remains available for FC bears in the area in other waste bins, where workers and members of the public improperly dispose of it. Additionally, the electric fence around the landfill was poorly built, so it is unable to withstand the effects of local weather conditions (e.g., heavy snowdrifts) and is not maintained effectively to prevent FC bear access. This situation has led to the continued pursuit of food waste at the landfill by FC bears.

No humans have been injured by grizzly bears in the oilfields or Deadhorse to date; however, by 2014, 20 of the 24 FC adults or independent subadult bears were lethally removed because they threatened humans or property. Seven of these FC bears were killed as management actions in 2001–2002, within two years after implementation of the large-scale restriction of bear access to food waste. In Yellowstone National Park, where park managers implemented similar garbage restrictions to address FC bear problems (see Craighead and Craighead 1971), a similar phenomenon was observed. Behaviors that led to grizzly bear mortality included a lack of wariness toward humans, destructive behavior, and breaking into buildings in search of anthropogenic food sources (Bentzen et al. 2014). In contrast, there were no NF bears killed by humans in defense of life and property or as management actions in the oilfield during this time frame.

2.4 Methods

Oil company SOs fill out paper copies of the GBSHR form in the field and submit them to ADF&G, usually < 24 h of a sighting occurrence. We collected these hard copy GBSHR forms and entered the data into a database in the program Access (version 15.0 Microsoft Corporation, 22 September 2015). We excluded any records that did not have a physical location recorded as either GPS coordinates or as a reported distance to an identifiable landscape feature, and records that did not have a reported date. If bear identification was not included on the report, the bear was categorized as UNK. We eliminated records that were duplicates or reports that were obviously of the same bear sighting at the same place and at the same time. We excluded any reports that were not legible or that contained contradictory information that prevented accurate and precise interpretation.

We used all 2,453 reported bear sightings. We categorized identified bears as NF or FC based on the results of the Bentzen et al. (2014) study: stable isotope analysis of 51 hair samples from 30 individual bears and observed feeding on anthropogenic food waste > 3 days per year. We also classified sightings as UNK and UNM bears, and then divided all sightings into a pre-food waste restriction time frame (1990–2000) and post-food waste restriction time frame (2001–2014) to produce a total of 8 subcategories (Table 2.1). We used GPS coordinates reported by SOs and reported bear distance to landscape features to project each bear's location from the distance and azimuth description provided by SOs to assign each sighting a latitude and longitude. Using spatial coordinates generated for each sighting, we used ArcGIS version 10.5 (ESRI, 15 December 2016) to create a geospatial data layer (i.e., point shapefile) to map all bear sighting locations. Bear locations were overlaid with geospatial data of prominent natural and human-made landscape features (Figure 2.4).

We then performed a near analysis (ArcGIS version 10.5, ESRI, 15 December 2016) to calculate distance between the bear location and the following prominent landscape features: road, river, facility, and the landfill. We chose to look at bear distance to road because the SOs reporting would be in their vehicles on the road system and generally as close to the bear as the road would allow them to get. Rivers were included because much of the quality natural forage for bears in the oilfields exists near the major river drainages that traverse the Arctic Coastal Plain. Facilities were chosen as a landscape feature to represent every structure present in the North Slope oilfields and Deadhorse. These structures included drill pads, processing facilities, and operation centers; all contained high concentrations of human activity. The landfill was selected as a landscape feature to test the hypothesis that, post-2001, FC bear sightings would be concentrated around the landfill because it was one of the few remaining areas where bears would have access to food waste. We hypothesized that all other bear categories would not change in spatial distribution in relation to the landfill. We estimated how the spatial distribution of FC, NF, UNK, and UNM bear sightings changed from pre- to post-2001 restriction of bear access to food waste using the effect size statistic, Hedges' g (Steidl et al. 1997, Nakagawa and Cuthill 2007). We calculated Hedges' g for each category using differences between control and treatment mean sighting distances divided by pooled category standard deviations to account for the differences in sample size for most biologically relevant and interpretable change in distances post-treatment (Hedges 1981, Maher et al. 2013). We interpreted the Hedges' g statistic according to the recommendations of Cohen (1977): small effect: ≤ 0.2, medium effect: $0.2 < g < 0.8$, and large effect: ≥ 0.8. The Hedges' g value provides an estimate of the number of standard deviations that the treatment mean differs from the control mean. We then performed a kernel density analysis (ArcGIS version 10.5, ESRI, 15 December 2016) to visualize areas with a high and low density of sighting points for each bear category to generate visually interpretable hot spot maps, with graduating shades of color to represent changes in bear location densities.

2.5 Results

Of the 47 individual, radio-collared bears recorded in the GBSHR, 47% ($n = 22$) were classified as FC and 53% ($n = 25$) were classified as NF. However, 82% ($n = 983$) of radio-collared bear observations recorded in the GBSHR consisted of FC bears (Table 2.1). Including the UNK and UNM sightings, UNK bears represented 49% (n = 1,189) of all reported sightings, and the vast majority of these (83%, n = 983) took place after 2001. The UNM sightings were reported the least (2%, n = 57) of all bear identification categories. The FC bear mean distance to landfill decreased by 7,318 m after 2001, a medium-low effect size of Hedges' g = 0.41 (SE ± 0.06) (Table 2.2), in comparison with NF bear mean distance to landfill, which decreased by 3,326 m, a low effect size of Hedges' g = 0.15 (SE ± 0.16) (Table 2.3). Food-conditioned bear mean distance to river increased (Hedges' g = 0.21 [SE ± 0.06]), and NF distance to river decreased (Hedges' g = 0.21 [SE ± 0.16]). Natural food bear mean distance to facility (Hedges' g = 0.24 [SE ± 0.16]) increased post-treatment. Mean distance to road for UNM bear decreased by 571 m, with a large effect size of Hedges' g = 0.75 (SE ± 0.33) (Table 2.5). The hot spot analysis illustrated high densities of FC bear sightings around the landfill, Deadhorse, and the Kuparuk Industrial Center (KIC) before 2001, and a concentration of FC bear sightings at the landfill and around Deadhorse after 2001 (Figure 2.5B). The hot spot analysis for NF, UNK, and UNM bears depicted sighting densities dispersed in proximity to the road system, with minimal change in distribution post-2001 (Figure. 2.5A, C, and D).

2.6 Discussion

Since the creation of the GBSHR, data gathered have functioned to influence the management decision-making process. Our analysis provided the first spatially and temporally explicit assessment of the dataset to quantify long-term trends in sighting characteristics, specifically regarding FC and NF bear categories and food waste management in an industrial setting. The GBSHR database documents bear sightings in a very remote, highly controlled landscape with a relatively dense network of roads that are patrolled continuously by oilfield

SOs. Considering that the SOs are trained and instructed to report grizzly bear sightings on a form specifically created for this purpose, our findings would be expected to have a high degree of accuracy when compared with reporting systems based on random, voluntary public reports and agency response to incidents (Wilson et al. 2005, Wilder et al. 2007, Morehouse and Boyce 2017). The GBSHR program is the longest running human-wildlife studies in the Arctic that includes known FC and NF bear identification categories, and it is one of the most modern as well. On the whole, managed landscapes with radio-collared grizzly bears no longer allow bear access to food waste in such a consistent and localized way.

Our results indicating that FC bear sightings occurred two to three times closer to the landfill after 2001 than other bear identification categories agreed with our hypothesis; however, our quantification of the extent of change was novel and provides useful information on how sightings of remaining FC bears persisted despite the killing of FC bears throughout the study period. The concentration of FC bear sightings to an average of 13 km from the landfill after 2001 suggests that restrictions on food waste access in other parts of the oilfield were effective. However, our findings also suggest that reducing access may not prevent FC females from teaching their cubs this foraging behavior, and a few isolated opportunities for bears to access anthropogenic food waste (i.e., landfill, Deadhorse dumpsters) can continue to foster a population of FC bears (Mazur and Seher 2007, Bentzen et al. 2014).

Studies conducted on black bear (*U. americanus*) habitat selection in areas with both low and high human densities have indicated that black bears will alternate foraging behavior in response to the availability of natural food sources by selecting areas with high-density human population in order to supplement nutritional needs in years of drought (Johnson et al. 2015, Laufenberg et al. 2018). Food-conditioned bears alternated foraging behavior between natural and anthropogenic food sources during our study period, but NF bears were never observed foraging on anthropogenic food waste.

The hot spot for FC bears near the Kuparuk Industrial Center (KIC) (Figure 2.5B) before 2001 may be explained by historic information on industry activities and logistics. Before the establishment of a permanent Kuparuk River Bridge in 2000, the temporary bridge over the Kuparuk River would be inundated by flood waters in early summer each year. Flooding would restrict road travel from Kuparuk and lead to temporary storage of garbage at the KIC while waiting for access to the landfill. Food-conditioned bears would commonly feed on this stored food waste, leading to FC bear sightings in the KIC area. The ability of the GBSHR to be used to identify sources of food waste based on density of reported FC bear sightings is evidence of its usefulness for management purposes and provides important insight on individual bear behavior.

The greater number of sighting reports for NF, UNK, and UNM bears post-2001 is partially due to the longer time frame—11 years pre-2001 and 14 years post-2001—but it is also the result of an expanding oilfield road network and increased anthropogenic activity predominantly west of the Deadhorse region. A similar phenomenon was observed in the Polar Bear Human Interaction Management System implemented by the United States Fish and Wildlife Service (USFWS). Increased polar bear sightings in the North Slope oilfields of Alaska were determined to be the result of increased human presence and activity, and increased bear use of terrestrial environments as a result of sea ice decline in the Arctic rather than an increase in bear population density, a decrease in bear wariness to humans, or other explanations that presumed another change in bear ecology (Craig J. Perham, USFWS, Personal Communication, 24 August 2017). The fact that the number of NF, UNK, and UNM bear sightings increased while FC bear sightings remained relatively constant indicates that, as the oilfield footprint expanded, it included the home ranges of more bears foraging naturally, increasing the likelihood that these bears would be sighted, in contrast to the FC bears, which continued foraging on food waste in the same specific areas and were killed to reduce conflict. The decrease in UNM bear distance to road post-treatment (Hedges' g = 0.75) was the greatest effect size difference of all bear identification categories; however, the small, yet increasing sample size of UNM bear sightings (n = 12, pre-2001 and n = 45, post-2001) is indicative of two things: (1) an expanding oilfield road system overlapping more UNM bear home ranges leading to a greater number of UNM bear sightings, and (2) the categorization of UNM bear implies that the bear was close enough to the road system for the SO to confirm that the bear did not have identifying markers; otherwise it would have been categorized as an UNK bear.

Craighead and Craighead (1971) reported that abrupt closure of landfills in Yellowstone National Park resulted in an increase in human-bear conflict issues, including human-caused bear mortality stemming from FC bears seeking food waste around human infrastructure. Similarly, a sudden increase in the killing of FC bears occurred following the restriction of bear access to food waste in the North Slope oilfields, but the absence of a sudden reduction in FC bear sightings in and around the landfill indicated that the surviving FC bears continued to access the landfill and reproduce. It is possible that the presence of adult FC bears excluded or moderated subadult FC bear use of the landfill, similar to ways in which adult bears, and specifically adult male bears, in other areas exclude subadult bears from using quality natural forage and anthropogenic sources (Egbert 1978, Gunther 1990, Olson et al. 1996). The absence of a sudden reduction in FC bear sightings after the removal of FC bears indicates that those foraging heavily on anthropogenic food waste were likely dominant bears that, upon removal, left a void open for subadult FC bears to occupy. It is unlikely that a NF bear became a FC bear in response to the removal of FC bears, as there is little crossover between NF and FC bear foraging strategies reported in the GBSHR and confirmed by genetic data from the ADF&G oilfield grizzly bear project.

Genetic analysis conducted as part of the oilfield grizzly bear project indicates that FC bears in the North Slope oilfields are almost entirely descendant from resident FC matriarchs that raised their cubs to forage on food waste, while resident NF matriarchs raised their cubs to forage solely on natural food sources (Richard T. Shideler, Personal Communication, 5 September 2017). Mazur and Seher (2007) observed that in black bears, the foraging behavior of the mother was the main predictor of the foraging behavior of the cubs once they reached adulthood, ruling out individual learning or a heritable temperamental predisposition as the primary means by which a bear becomes food-conditioned. This supports the theory that FC bears are recruited by their mothers rather than spontaneous conversion of NF bears.

Previous research conducted on grizzly bears in proximity to industrial activity reported temporary displacement from the immediate vicinity of drilling sites, loss of habitat due to drilling (Harding and Nagy 1980), and road avoidance of approximately 100 m (McLellan and Shackleton 1988). Peek et al. (1987) predicted that habituated bears may be less affected by oilfield activities due to their continued use of regional habitat, yet more subject to human-caused bear mortality as a result of their lack of wariness toward humans following habituation. Our results indicated that a certain degree of habituation may allow grizzly bears to coexist and forage naturally within an industrial setting in the Arctic. Food conditioning leads to an increased risk to human safety or property and consequently higher human-caused bear mortality (Bentzen et al. 2014). Natural food bears, and many UNK and UNM bears, can be considered habituated to oilfield activities and commonly access natural bear habitat by crossing oilfield roads and drill pads without restriction to travel. This can be seen in the small effect size (Hedges' g = 0.01) in reported NF bear-sighting distance to roads between time periods, indicating that these bears have likely been habituated to oilfield activity throughout the study period, and have continued to use habitat in the oilfields in much the same way without the need for removal.

Deadhorse is not officially a part of the oilfield lease land and therefore is not patrolled by oilfield SOs. Public Safety Officers there respond to bear issues in the community, but they do not contribute actively to the GBSHR database despite numerous human-bear conflict issues largely related to the presence of unsecured food waste and the proximity of the Sagavanirktok River delta, a major drainage in the region (Figure 2.3). The presence of a hot spot in the Deadhorse region is likely an underestimate of bear sightings in Deadhorse, most of which would be FC bears since it is uncommon for NF, UNK, and UNM bears to be seen in town and their mean distance to the landfill exceeds 25 km. The distance from the landfill to Deadhorse is approximately 10 km, and mean FC bear distance to the landfill post-2001 was 13 km, with hot spot maps indicating a clear occurrence of FC bear sightings in the Deadhorse region. Grizzly Bear Sighting and Hazing Reports from Deadhorse are either incidental or reported by oilfield SOs from drill pads nearby.

It is possible that some FC bears have benefitted from an artificially rich diet of food waste by attaining an increased body size and reproductive capability, but their increased mortality rate may marginalize nutritional gains resulting from FC behavior. Weeden (1971) predicted that the primary effects of oil exploration such as habitat loss, den disturbance, and displacement were likely insignificant compared with the secondary effects of increased habituation to humans. Our study suggests that bear habituation to oilfield activities can allow bears to use habitat within the oilfields without increasing their chances of human-caused bear mortality if food waste is kept secure from bear access and an active hazing effort is in place. Hazing has been shown to maintain, and in some cases increase, bear wariness toward humans, but hazing is not considered effective in preventing FC bears from accessing improperly secured food waste (Hopkins et al. 2010, Mazur 2010). It is likely that hazing of NF bears in the oilfields helped to prevent NF bears from becoming FC in some cases. This can be seen in the post-treatment increase in NF bear distance to facilities (Hedges' $g = 0.24$) while NF bear distance to rivers decreased (Hedges' $g = 0.21$), indicating that the proactive bear management effort helped prevent NF bears from adopting a novel FC foraging behavior. If food waste is not secured and is consistently available, habituated bears foraging in the area have the potential to exhibit a food-conditioned foraging strategy, especially during periods of poor natural food availability, which would greatly increase the chances of negative human-bear encounters and human-caused bear mortality.

2.7 Management Implications

Grizzly Bear Sighting and Hazing Reports can be used to understand the history of grizzly bear sightings and human-bear interactions in the North Slope oilfields while also providing some valuable insights into how bear foraging habits may influence where and when bears interface with anthropogenic activity in the Arctic. Security officers would generally submit reports to ADF&G < 24 h of a sighting occurrence, allowing rapid communication of field observations to bear managers. This practice can facilitate proactive response by managers, and in return, managers can quickly advise SOs on management actions. Reports can quickly be categorized to produce hot spot maps, which are much more visually interpretable than tabular data, and can be used as an effective management and communication tool. Managers benefit from a better understanding of where bear sightings are occurring in real time, and in annual reporting, identifying regions of potential human-bear conflict and proactively addressing the causes of such sighting densities. These hot spot maps can also be used to show how bear sighting densities have changed over time, and ArcGIS near analysis can be used to calculate effect size to quantify how sighting characteristics change in relation to landscape features as anthropogenic activity continues to expand in the oilfields.

Within the scope of the oilfield grizzly bear project, this study indicates that industrial activity in the Arctic and in other landscapes can be managed for human coexistence with grizzly bears if (1) food waste is handled and disposed of in a way that prevents bears from accessing it, and (2) a bear management plan is enacted that includes a bear response team utilizing hazing or aversive conditioning techniques, and a reporting system such as the GBSHR, with adequate local engagement and regional participation.

The lack of a reporting system in Deadhorse is an example of how difficult it can be to monitor and address human-bear conflict issues when there is insufficient documentation of incidents. We recommend that Deadhorse adopt the GBSHR system and contribute bear-sighting information to ADF&G as a way of quantifying its level of human-bear conflict in order to identify and address problem areas. Other managed landscapes, such as industrial lease land or state parks, could benefit from a similar reporting system. If the reporting system is standardized, it could be used to compare bear sightings between different regions, different habitats, and even bear species for a better understanding of the factors that contribute to human-bear conflicts. We recommend that future reporting systems transition to digital format to expedite data submission to management and streamline analysis.

The long-term availability of food waste to grizzly bears in the North Slope oilfields has led to human-caused bear mortality and enduring effort from SOs to respond to and monitor FC bear activity (Bentzen et al. 2014). In order to decrease human-bear conflict and associated resource expenditure, we recommend that future management of human activity in the Arctic includes taking steps to reduce or eliminate food-conditioning of bears. This principle can be applied more broadly to landscapes outside of the Arctic and to other bear species. Our study contributes to an increasing body of knowledge that indicates that food conditioning of bears leads to human-caused bear mortality and negative human-bear encounters. Proper disposal of food waste, the effective use of electric fencing, and deterrent methods such as hazing and aversive conditioning can proactively prevent or reduce these negative encounters.

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2.9 Figures

Bear ID# (ADF&G use)______ 6/2011 rev.

OILFIELD GRIZZLY OBSERVATION FORM

OBSERVER_________________________ **COMPANY/AGENCY**_______________

OBSERVATION DATE_____________ **TIME:** Start______ Stop_______________

OBSERVATION FROM: Vehicle_____ Ground_____ Building_____ Other____________

OBSERVER DISTANCE FROM BEAR____________________meters

GENERAL LOCATION: Deadhorse___ EOA___ WOA___ Kuparuk___ Endicott_____

Milne____ Badami___ Alpine____ Pt. Thomson___ TAPS (MP #)_____

Other (latitude/longitude if known)____

SPECIFIC LOCATION [*Example: 500 meters N of DS 14*]: ___________________meters

_________[direction] of ___________________________________[facility name]

DUMPSTER PRESENT? Yes_________ No_______ Unknown________

WEATHER: ______°F Wind direction__________ at _____________mph

Clear/partly cloudy_____ rain______ fog______ snow______

BEAR IDENTIFICATION: EAR FLAG COLOR [***Note:*** *right & left of bear, not observer*]

___________Color right ___________Color left NATURAL MARKINGS [scars, torn ears, ETC.]____

OTHER BEARS PRESENT? None_____ No. of new cubs_______ No. of yearlings_____

No. of 2 year olds_______ Number of other adults_________ No. unknown_______

BEAR ACTIVITY WHEN FIRST SEEN: Resting____ Feeding (natural food) _____

Feeding (garbage)______ Traveling______ Traveling/feeding______

Other [describe]:____

BEAR REACTION TO OBSERVER: Ignore_____ Approach_____ Avoid_______

Were other people in area (not with observer)? Yes_____ No______ Unknown______

BEAR REACTION TO OTHER PEOPLE: Ignore_____ Approach_____ Avoid_______

REACTION COMMENTS____

____

DETERRENCE ACTION TAKEN? Yes_________ No__________

If yes, did you use: Horn_____ Siren_____ Rubber slug_____ Bean bag_____

Cracker shell______ Other [describe] ___________________________________

BEAR'S REACTION TO DETERRENT: Ignore____ Approach_____ Withdraw_______

ADDITIONAL REMARKS____

____

____

Dick Shideler, Alaska Dept. Fish & Game; FAX 907-459-7332, or email dick.shideler@alaska.gov

Figure 2.1. Grizzly Bear Sighting and Hazing Report form.

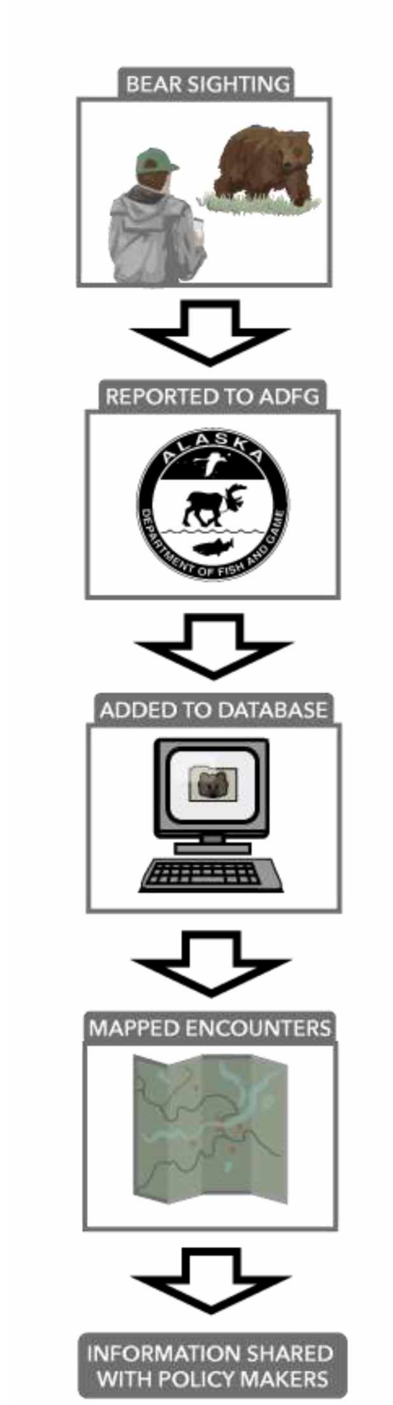


Figure 2.2 Grizzly bear sightings are documented by oilfield security officers on the Grizzly Bear Sighting and Hazing Report form and submitted to the Alaska Department of Fish and Game to be digitized, mapped, and then analyzed for management decision making.

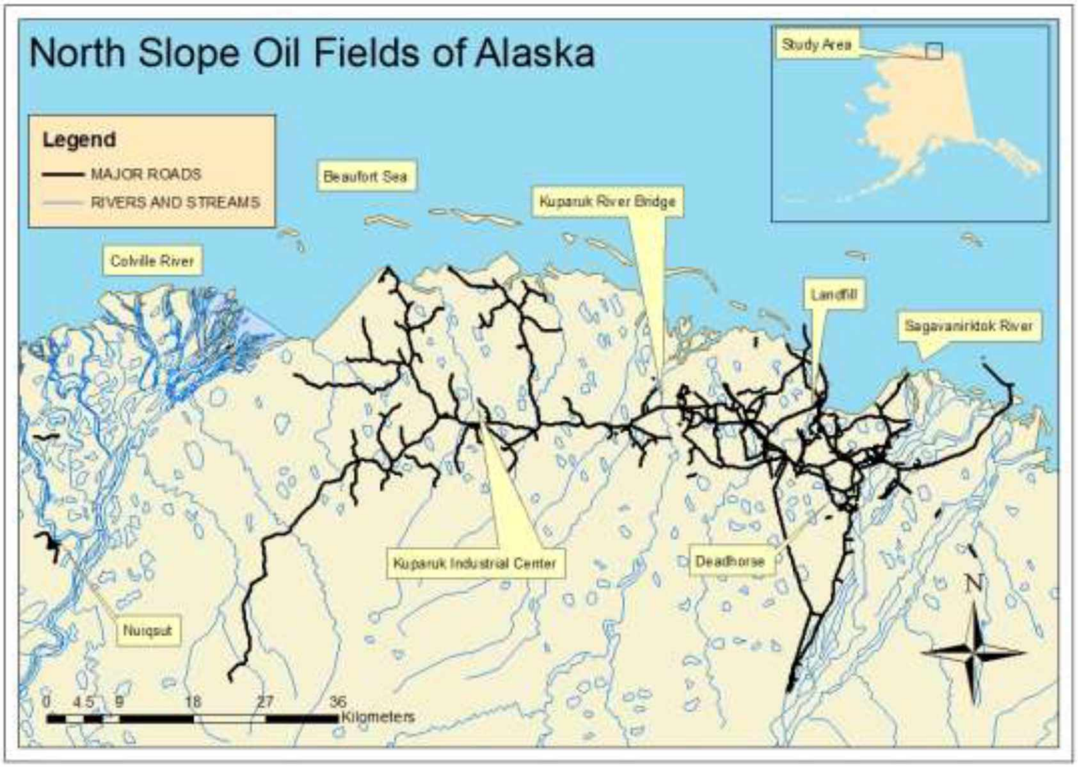
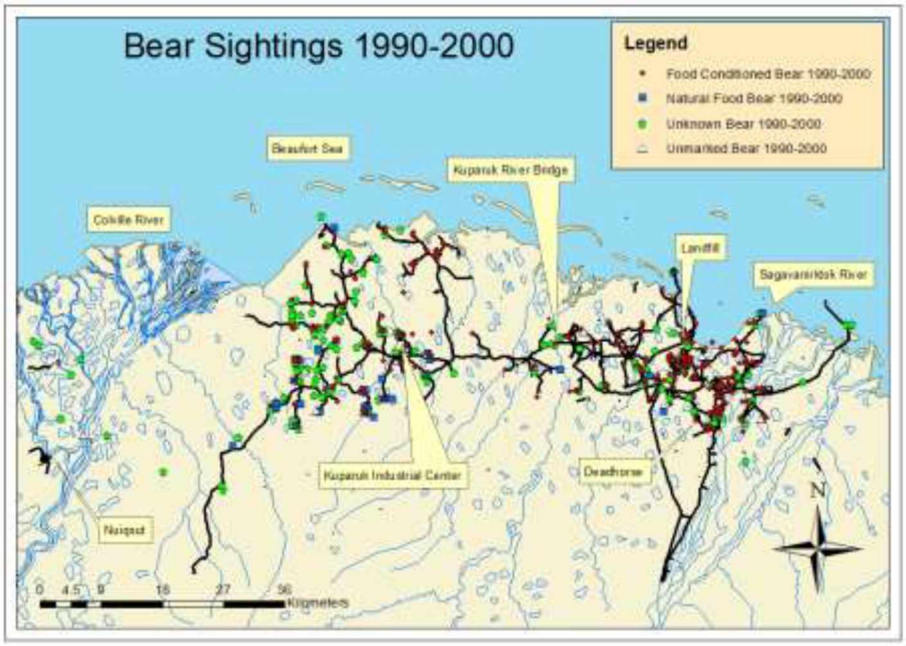


Figure 2.3. Grizzly Bear Sighting and Hazing Report form study area, North Slope oilfields of Alaska (USA).



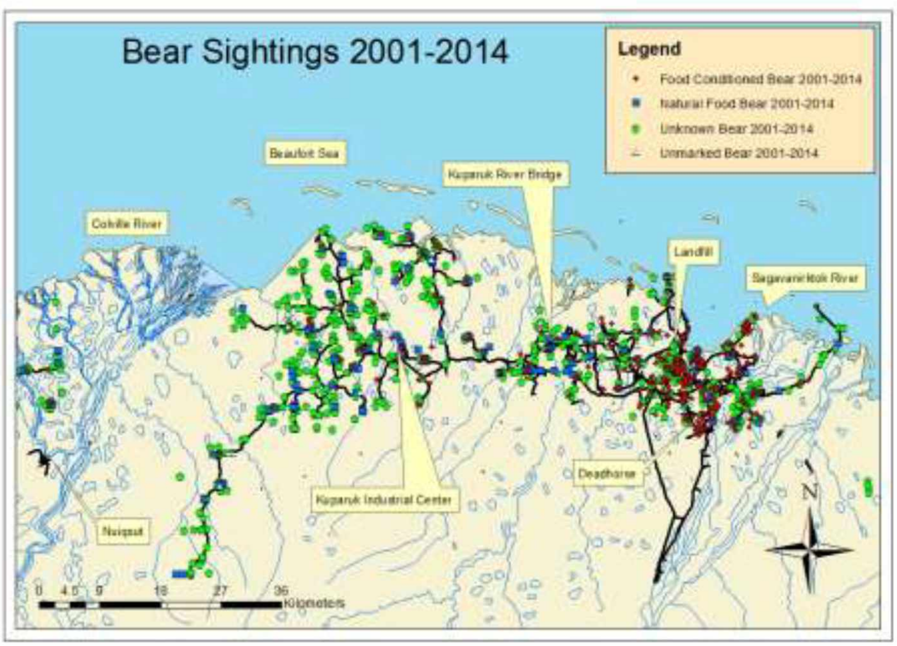
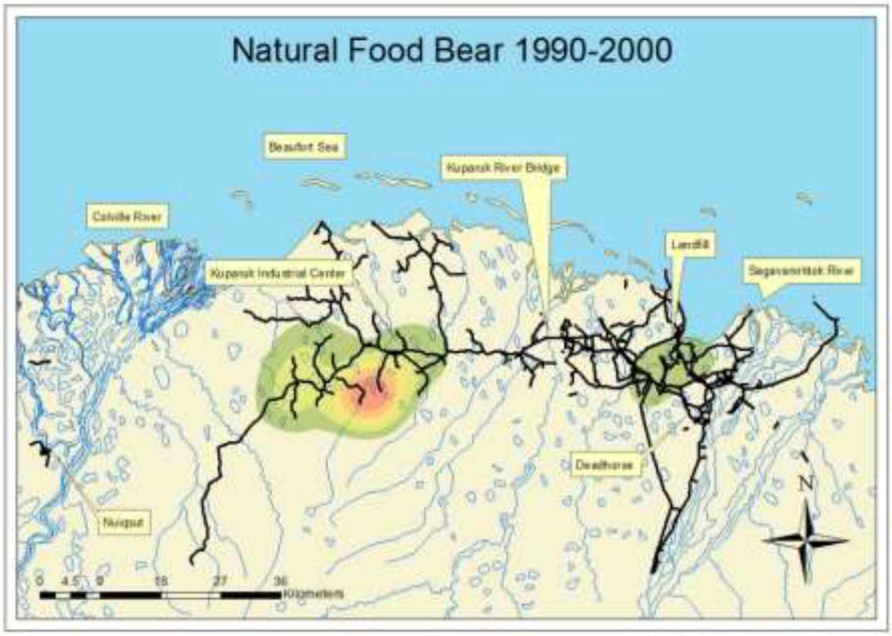


Figure 2.4. Map of reported bear sightings categorized by bear identity: food-conditioned, natural food, unknown, and unmarked bears in the North Slope oilfields of Alaska before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste.



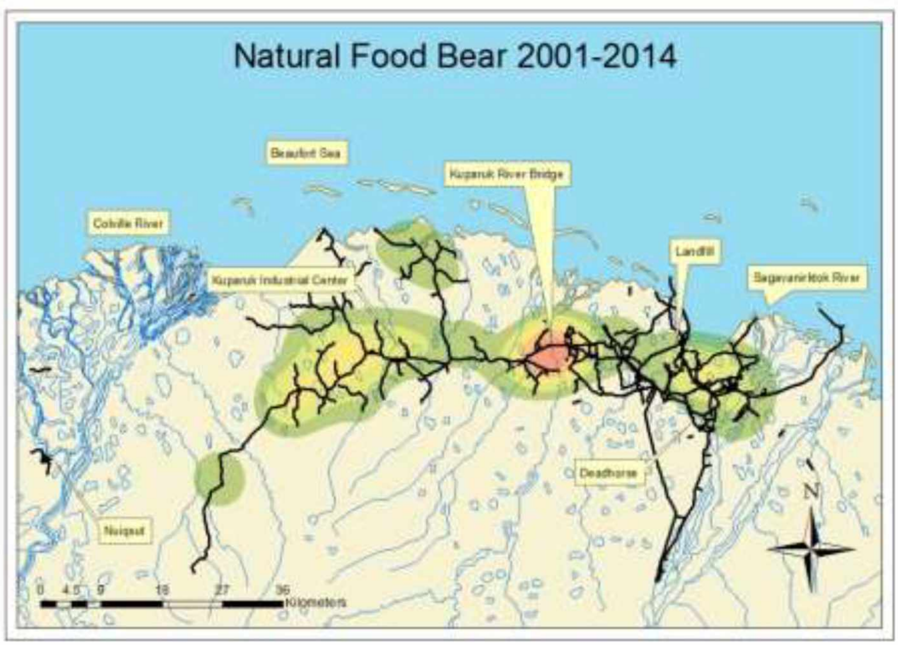


Figure 2.5A. Kernel density analysis of reported grizzly bear sightings to produce hot spot maps of natural food bear locations, before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste in the North Slope oilfields of Alaska.

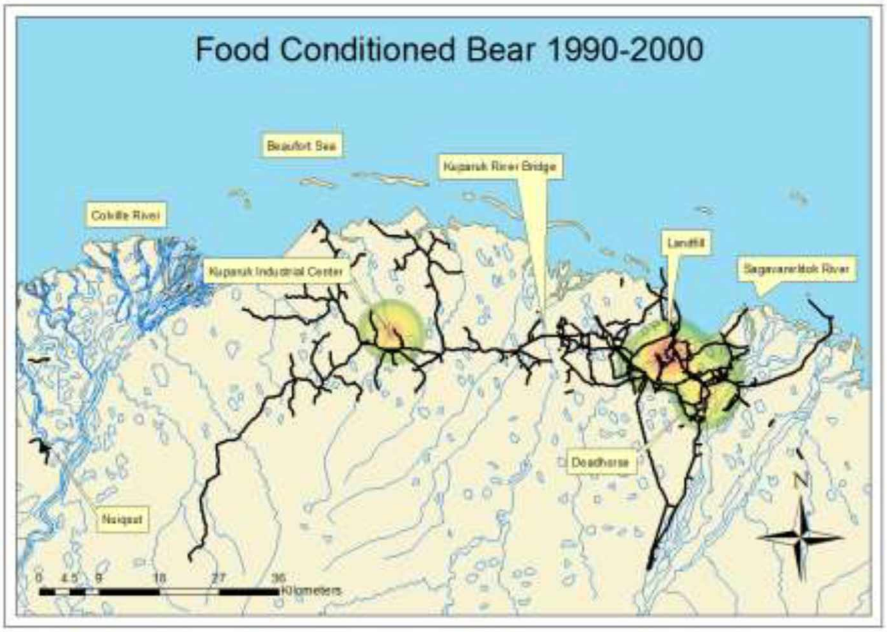
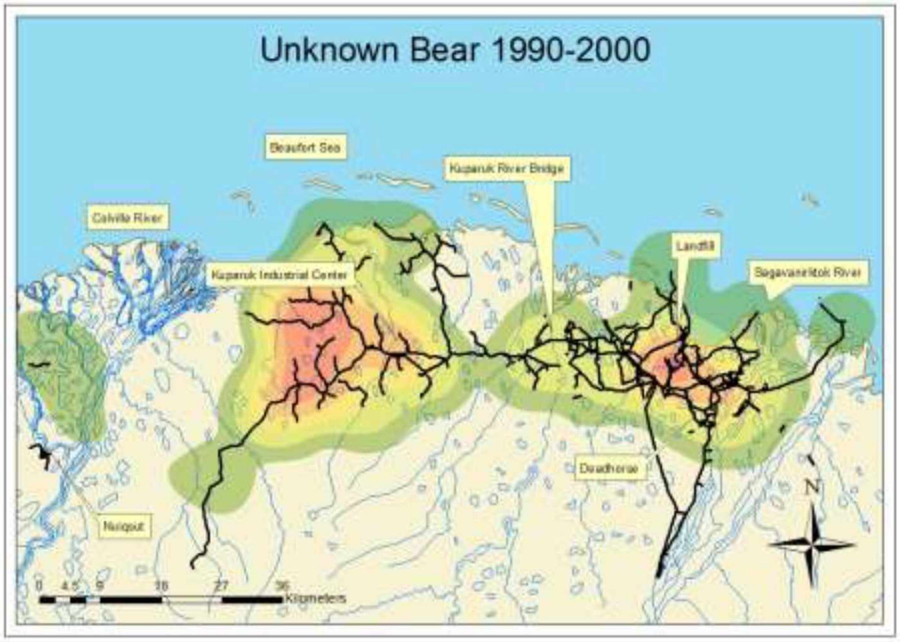


Figure 2.5B. Kernel density analysis of reported grizzly bear sightings to produce hot spot maps of food conditioned bear locations, before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste in the North Slope oilfields of Alaska.



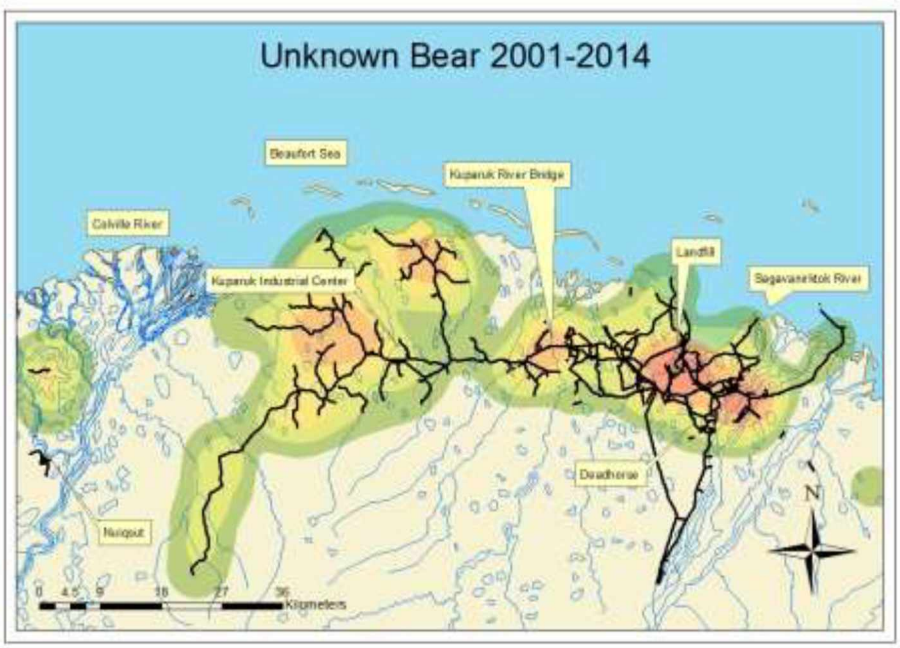


Figure 2.5C. Kernel density analysis of reported grizzly bear sightings to produce hot spot maps of unknown bear locations, before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste in the North Slope oilfields of Alaska.

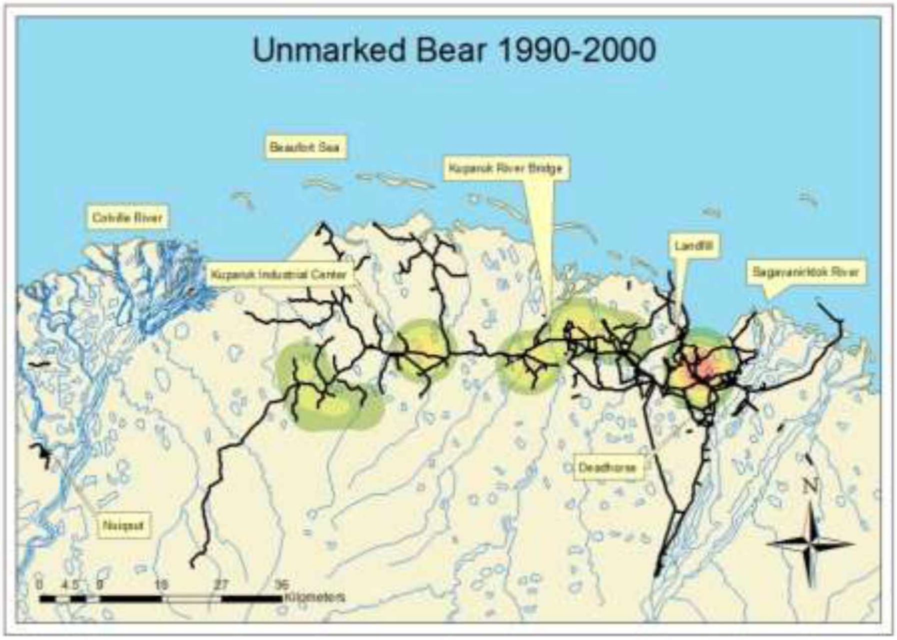


Figure 2.5D. Kernel density analysis of reported grizzly bear sightings to produce hot spot maps of unmarked bear locations, before (1990–2000) and after (2001–2014) large-scale restriction of bear access to food waste in the North Slope oilfields of Alaska.

2.10 Tables

Table 2.1. Number of individual radio-collared food-conditioned and natural food grizzly bears with percentages, and number of reported food-conditioned, natural food, unknown and unmarked bears with percentages from before (1990–2000) and after (2001–2014) restriction of bear access to food waste in the North Slope oilfields of Alaska.

	Individual Bears		Reported Sightings	
	1990 - 2000			
Bear ID	#	%	#	%
Food-Conditioned	19	63%	454	63%
Natural Food	11	37%	51	7%
Unknown	NA	NA	206	28%
Unmarked	NA	NA	12	2%
	2001 - 2014			
Food-Conditioned	11	39%	528	30%
Natural Food	17	61%	174	10%
Unknown	NA	NA	983	57%
Unmarked	NA	NA	45	3%

Table 2.2. Mean reported food-conditioned bear distance to landscape feature (meters ± standard error [SE]) with effect size (ES), and Hedges' g ± SE before (1990–2000) vs. after (2001–2014) restriction of bear access to food waste in the North Slope oilfields of Alaska.

	1990–2000	2001–2014		
n	454	528		
Landscape Feature	mean (±SE)		ES	Hedges' g (±SE)
Road	275 (±13)	363 (±26)	88	0.18 (±0.06)
Facility	213 (±16)	307 (±28)	94	0.18 (±0.06)
River	525 (±23)	637 (±25)	112	0.21 (±0.06)
Landfill	20,044 (±899)	12,726 (±731)	7,318	0.41 (±0.06)

Table 2.3. Mean reported natural food bear distance to landscape feature (meters ± standard error [SE]) with effect size (ES), and Hedges' g ± SE before (1990–2000) vs. after (2001–2014) restriction of bear access to food waste in the North Slope oilfields of Alaska.

	1990-2000	2001-2014		
n	51	174		
Landscape Feature	mean (±SE)		ES	Hedges' g (±SE)
Road	393 (±57)	401 (±50)	8	0.01 (±0.16)
Facility	331 (±58)	499 (±58)	168	0.24 (±0.16)
River	655 (±76)	553 (±36)	102	0.21 (±0.16)
Landfill	38,185 (±2,597)	34,859 (±1,702)	3,326	0.15 (±0.16)

Table 2.4. Mean reported unknown bear distance to landscape feature (meters ± standard error [SE]) with effect size (ES), and Hedges' g ± SE before (1990–2000) vs. after (2001–2014) restriction of bear access to food waste in the North Slope oilfields of Alaska.

	1990–2000	2001–2014		
n	206	983		
Landscape Feature	mean (±SE)		ES	Hedges' g (±SE)
Road	605 (±75)	582 (±28)	23	0.02 (±0.08)
Facility	569 (±65)	676 (±37)	107	0.10 (±0.08)
River	570 (±45)	578 (±18)	8	0.01 (±0.08)
Landfill	36,535 (±1,600)	34,460 (±805)	2,075	0.08 (±0.08)

Table 2.5. Mean reported unmarked bear distance to landscape feature (meters ± standard error [SE]) with effect size (ES), and Hedges' g ± SE before (1990–2000) vs. after (2001–2014) restriction of bear access to food waste in the North Slope oilfields of Alaska.

	1990-2000	2001-2014		
n	12	45		
Landscape Feature	mean (±SE)		ES	Hedges' g (±SE)
Road	816 (±461)	245 (±38)	571	0.75 (±0.33)
Facility	236 (±86)	280 (±76)	44	0.09 (±0.33)
River	654 (±160)	713 (±83)	59	0.10 (±0.33)
Landfill	28,573 (±7,745)	25,825 (±3,443)	2,748	0.11 (±0.33)

CHAPTER 3: USE OF FORWARD-LOOKING INFRARED FOR BEAR DEN DETECTION IN THE ALASKA ARCTIC[2]

3.1 Abstract

Industrial off-road activity in the winter overlaps quality winter denning habitat of polar bear (*Ursus maritimus)* and grizzly bear (*U. arctos*) in the North Slope oilfields of Alaska. To prevent the disturbance of bear dens, managers have attempted to use forward-looking infrared (FLIR) to locate dens, but the effectiveness of FLIR techniques under different environmental conditions is unresolved. To evaluate the efficacy of FLIR techniques and optimize use for arctic bear den detection, we equipped an unmanned aircraft system (UAS) with a FLIR camera and conducted routine observations of artificial polar bear (APD) and grizzly bear (AGD) dens from horizontal and vertical perspectives, at distances ≤ 100 m, from December 2016 to April 2017. We recorded physical characteristics of each artificial den and weather conditions during each observation period. We captured 291 images and classified each as a detection or non-detection based on the number of image pixels representative of a bear den "hot spot." We used logistic regression to model the effects of 11 weather conditions on the odds of detection. We found that UAS-FLIR detects APDs 2 times better than it detects AGDs, vertical detections are 4 times better than horizontal, and that weather affects odds of detection between 50 and 100 m distance. Lower air temperature and wind speed, and the absence of precipitation and solar radiation increased odds of detection for APDs. An increase in air temperature of 1°C lowered the odds of detection by 12% for APDs and by 8% for AGDs, but physical den characteristics such as den snow wall thickness determined detectability of AGDs. We found that UAS-FLIR surveys can be effective if conducted in November (AGDs) and January (APDs), on cold, clear days, with calm

[2]Pedersen, N.J., T.J. Brinkman, R.T. Shideler, and C.J Perham. 2019. Use of Forward-Looking Infrared for Bear Den Detection in the Alaska Arctic. Prepared for submission to *Ursus*.

winds, during hours of low solar radiation. We "ground-truthed" and demonstrated our technique on 1 occupied polar bear den and 2 occupied grizzly bear dens. Images resulting from UAS-FLIR detection of arctic bear dens are best interpreted by experts in this field of technology and should be confirmed by a secondary method.

3.2 Introduction

Winter dormancy in grizzly bear (*Ursus arctos*) and polar bear (*U. maritimus*) is a complex ecological strategy to reduce energy expenditures during periods of unfavorable environmental conditions (Watts 1990). Grizzly bears of both sexes and all age classes use winter dens, and pregnant females give birth in them (Manchi and Swenson 2005), whereas only pregnant female polar bears exhibit denning behavior (Harrington 1968, Jonkel et al. 1972, Lentfer 1975, Watts 1990). The denning period is one of the most vulnerable stages of the bear reproductive cycle (Amstrup 1993, Linnell et al. 2000). Pregnant female polar bears of the Southern Beaufort Sea stock establish maternal dens within large drifts of snow in preparation to give birth to and raise viable young (Amstrup et al. 2004). They enter the den in late November to early January, give birth in mid-winter, and remain in the den until March or April, when the cubs are ready to emerge and survive the arctic spring conditions (Blix and Lentfer 1979, Amstrup 1993, Amstrup and Gardner 1994, Smith et al. 2007). Grizzly bears dig earthen dens between late-September and early-November and exit dens between March and May, with females that are not pregnant and males entering dens later in the season and exiting earlier than pregnant females (Shideler and Hechtel 2000). Pregnant bears give birth in the den during the winter to protect their young from the harsh winter conditions during their most vulnerable stage of life. If disturbed, a bear may abandon its den resulting in higher bear mortality, family dissolution, and subsequent cub mortality due to exposure, starvation, or intraspecific predation

(Lentfer and Hensel 1980, Stirling 1990, Stirling and Andriashek 1992, Amstrup 1993, Amstrup and Gardner 1994, Swenson et al. 1997, Linnell et al. 2000).

Since the 1970s, extensive petroleum exploration and extraction on the Alaska North Slope (USA) have occurred in denning habitat for both polar bears and grizzly bears and will likely expand in the future. The U.S. Fish and Wildlife Service (USFWS) and the Alaska Department of Fish and Game (ADF&G) have collaborated with industry in researching safe and effective methods to locate and avoid occupied bear dens, which is necessary to minimize negative human-bear interactions and conserve populations of arctic bears. This study is a part of that ongoing process.

Losses in critical sea ice habitat have placed the long-term viability of the polar bear in question, resulting in "threatened" status under the Endangered Species Act (ESA) since 2008 (Federal Register 2013). Shifting weather patterns and sea ice regimes are forcing polar bears to select terrestrial den habitat in increasing numbers, raising the chances of adverse human-bear interactions with residents of coastal villages and personnel associated with industrial activity (Amstrup and Gardner 1994, Fischbach et al. 2007). It is crucial that the oil industry has reliable protocols in place to locate and avoid occupied dens during development activities in the Arctic. The USFWS manages the southern Beaufort Sea polar bear stock on the Alaska North Slope and works with the oil and gas industry to minimize impacts to maternal polar bear dens through federal acts, such as the Marine Mammal Protection Act and the ESA, where one mitigation measure is a federally codified regulation (§18.128 50 €5 CFR Ch. 1) requiring a 1.6 km (1 mile) buffer zone around known polar bear dens.

On the North Slope, grizzly bears live in relatively low densities and have correspondingly large individual home ranges (Reynolds 1980), as well as lower reproductive rates than more southerly North American grizzly bear populations (Reynolds 1980, Craighead et al. 1995, Shideler and Hechtel 2000). The expansive area that these bears inhabit, as well as the behavior of both males and females entering winter dens, increases the chances that anthropogenic activity will encounter an occupied grizzly bear den, and the slow reproductive rate of grizzly bears increases the population's vulnerability to disturbance (Reynolds 1980). The ADF&G manages grizzly bear populations in Alaska; however, the Alaska Department of Natural Resources and the U.S. Bureau of Land Management have specific permit stipulations to prevent activity taking place within a 0.8-km (0.5-mile) buffer zone around identified occupied grizzly bear dens on state and federal land, respectively. These buffer zones around occupied polar bear and grizzly bear dens are established primarily for conservation purposes, but also address safety concerns for people working near disturbed dens. Such disturbances may instigate negative human-bear interactions that could result in the injury or death of involved people or bears (Madhusudan 2003, Naughton-Treves et al. 2003, Löe and Röskaft 2004, Voorhees et al. 2014).

Polar bear denning habitat is associated with landscape features that allow drifting snow to accumulate deep enough for excavation (Liston et al. 2016). This accumulation of drifting snow occurs on barrier islands, in linear coastal features, and in riverbank habitats that are widely dispersed and sometimes difficult to differentiate from the relatively uniform, flat terrain of the surrounding coastal plain (Benson 1982, Amstrup 1993, Amstrup and Gardner 1994, Durner et al. 2001, 2003). Grizzly bear denning habitat can be even more difficult to identify, as it constitutes a variety of landscape features. Common den habitat for grizzly bears includes riverbanks and terraces, sand dunes, pingos, and other earthen features that provide relief in the landscape (Shideler and Hechtel 2000). Den entrances are often discrete, and they are quickly covered by drifting snow, which can impede visual den detection techniques (Ramsay and Stirling 1990, Amstrup and Gardner 1994, Clark et al. 1997). For this reason, it is essential to identify and map suitable den habitat prior to attempting to locate occupied dens (Amstrup 1993, Durner et al. 2001, 2003, Blank 2012, Liston et al. 2016).

3.2.1 Forward-Looking Infrared

Forward-looking infrared (FLIR) cameras can detect minor heat differences in the landscape by measuring *emissivity*, which is the ability of a substance to release thermal energy (Hyll 2012). Forward-looking infrared technology has been effectively used to locate dens in areas where quality den habitat intersects industrial development (Amstrup et al. 2004). The USFWS has used FLIR techniques to detect polar bear dens in advance of industrial operations on the North Slope of Alaska since 2004 (Craig J. Perham, USFWS, personal communication, 12 December 2018). Sensors on FLIR can measure temperature differences as little as 0.1°C (Amstrup et al. 2004) and produce an image that assigns color scales to represent relative surface temperature differences. Polar bear den interiors can be 30°C higher than outside air temperatures, and the snow surface temperature above the den can be 10°C warmer than surrounding snow (Watts 1983). Watts (1990) indicated that denned grizzly bears can emit less than or equal heat. Body heat creates a “hot spot” that appears as a discrete cluster of pixels on the surface above the den snow wall (or at the den entrance in the case of grizzly bears) where it is warmer than its surroundings. Given that the FLIR technology can detect as little as a 0.1°C difference in surface temperature, a bear den should produce a hot spot visible on the FLIR imagery. However, this is not always the case.

Previous studies on the effectiveness of FLIR imagery have documented both false positives, where hot spots are detected without occupied dens, and false negatives, where hot spots are not found on occupied dens. False positives occur because landscape structures can generate wind friction, absorb and re-emit solar radiation, or have substantially different emissivity that can be confused with the infrared (IR) signature of an occupied den (Amstrup et al. 2004). Weather conditions can inhibit the ability of FLIR sensors to differentiate temperatures on the snow surface, which will result in a false negative. Solar radiation can saturate FLIR imagery with reflectance from the snow surface and wash out the heat signature from the surrounding snow. Fog, rain, or snow may obscure the heat signature because the FLIR sensor will register the atmospheric particulate instead of the snow surface temperature (Amstrup et al. 2004, Robinson et al. 2014). False negatives are a much greater conservation and safety concern than false positives because occupied bear dens are not detected. We must understand the relative influence of environmental factors on odds of detection to minimize the occurrence of false negatives if FLIR technology is to be an effective tool for bear den detection in the Arctic.

Past findings have highlighted the potential for FLIR imagery to detect dens, but more research is needed to optimize techniques by advancing knowledge on what the ideal environmental conditions are for den detection and how adverse environmental conditions influence the odds of den detection. Amstrup et al. (2004) used FLIR cameras mounted on a helicopter to detect heat signatures of radio-collared polar bear maternal dens. Robinson et al. (2014) continued to evaluate optimal conditions for using hand-held FLIR cameras, and their limitations, for detecting human-made (artificial) dens for ground-based observations. Shideler and Perham (2013) used aircraft-mounted and hand-held ground-based FLIR imagers to evaluate den detection techniques and develop protocols for managers. Each of these previous studies revealed limitations on the effectiveness of FLIR cameras under varying ambient conditions that may influence odds of detection; however, the studies also highlighted opportunities for improvement. Amstrup et al. (2004) and Shideler and Perham (2013) noted that logistical issues hindered adequate data collection, which prevented precise and conclusive results on how environmental factors affected the odds of detection. Airborne FLIR camera surveys had to be scheduled months in advance, which prevented surveys during optimal weather conditions. A lack of consistent helicopter specifications for FLIR camera utility, and the prohibitive cost of charter and rentals, led Shideler and Perham (2013) to recommend testing the efficacy of unmanned aircraft systems (UASs) to overcome some of the obstacles they encountered. These studies found that the benefits of using a ground-based FLIR system came with significant costs, such as image interference from convection and blowing snow that inhibited detection. Also, a study by Robinson et al. (2014) was conducted in March, at the end of the polar bear denning season, and was thus of less practical utility for industry. At this time, snow walls would be at their thickest, and longer daylight periods would reduce the FLIR camera's effectiveness. Since the study lasted only 19 days, it could not capture the environmental and den structure variability across the entire denning season, particularly in December and January when industry needs to detect occupied bear dens as it begins winter activities (e.g., constructing ice roads).

3.2.2 Unmanned Aircraft Systems (UASs)

In order to overcome technical and logistical problems of earlier studies, we employed a FLIR-equipped UAS to obtain a greater sample of artificial polar bear and grizzly bear dens and to model the relative effects of environmental variables on odds of den detection. We hypothesized that the vertical perspective from an aerial platform should yield better results than a horizontal perspective due to heat dissipation through the snow wall above the den or den entrance, and that a horizontal perspective creates opportunity for increased interference from the friction of snow blowing across the den surface. From a vertically perpendicular perspective an occupied den produces a circular heat signature that is discernable from the surrounding environment due to its size, shape, and differential temperature. From the horizontal perspective, the heat escaping from the den snow wall surface appears as a “heat horizon,” yielding a much smaller heat signature that is elongated and difficult to discern from features that reflect solar radiation or generate friction in the landscape (e.g., wind lips, cornices).

Fixed-wing aircraft and helicopters equipped with FLIR cameras can survey large swaths of habitat from the vertical perspective, but it is expensive to conduct these flights for routine monitoring purposes, and aircraft are not always readily available when weather conditions are optimal. Fixed-wing aircraft are unable to hover above suspected den locations, and it can be challenging to get an accurate den location coordinate even with a gimbal-mounted, laser-guided system. Helicopters can hover and acquire an image from a stationary point, but access to helicopters that can accommodate FLIR equipment in the study area has been limited. Above all, manned aircraft pose a considerably greater risk to pilots and observers in arctic winter conditions compared with an UAS, which can accomplish many of the same functions without the associated risks and higher costs. Because UAS-FLIR platforms are cheaper and easier to deploy, they can foster a greater sample size of observations across variable environmental conditions.

The goal of this study was to further develop FLIR technology to detect grizzly bear and polar bear dens using a UAS platform. Our objective was to obtain a sample of artificial bear den UAS-FLIR imagery, across the polar bear den season (December to April), to (1) identify the critical differences in UAS-FLIR detection of grizzly bear and polar bear dens from horizontal and vertical perspectives; (2) model the relative influence of environmental variables on a UAS-FLIR system’s ability to detect artificial bear dens, that closely simulate the dimensions and temperatures of occupied bear dens, by obtaining a robust collection of imagery under varying environmental conditions; and (3) opportunistically collect imagery of occupied bear dens to demonstrate the ability of our UAS-FLIR to survey and monitor bear dens in arctic winter conditions and to compare to imagery of artificial dens.

3.3 Study Area

The grizzly bear reaches the northwestern limit of its range along the Alaska coast of the Beaufort Sea (Gibeau et al. 2000, Shideler and Hechtel 2000). This study took place in suitable bear denning habitat at two separate locations within the Kuparuk oilfield region of the North Slope oilfields, Alaska (Figure 3.1): the Kuparuk Industrial Center (KIC) and Drill Site 2M (DS2M). The climate in this region consists of long, cold winters with a mean temperature of -30°C, and short, cool summers with a mean temperature of 13°C. Light to moderate winter precipitation accumulates to an average snow depth of 30–40 cm, with wind drifts reaching 15 m deep in some areas due to strong, prevailing southwesterly and northeasterly winds that frequently reach speeds of > 48 kph. Winter snowpack begins to accumulate in October and melts away by mid-May, with larger snowdrifts remaining until June. The constant wind results in blowing, granular snow on the snow surface, which causes drifting and friction across irregular terrain surfaces. Coastal weather influence contributes to a low temperature-dew point spread that results in the presence of atmospheric fog and other suspended particulates. At this northern latitude, the sun sets in late-November and does not rise above the horizon again until late-January. During this two-month time period, darkness is interrupted by a brief period of civil twilight at mid-day when visibility is improved but there is no direct solar radiation. Once the sun returns, periods of morning and afternoon civil twilight are interrupted by increasing amounts of daylight.

The DS2M is a drill site located in the Kuparuk oilfield subunit, approximately 600 m north of Kalubik Creek. We established artificial polar bear den (APD) #1 within a large snowdrift that accumulates each winter on a southwest-facing aspect of the creek bed. We established artificial grizzly bear den (AGD) #1 within the bank soil of the creek bed. The Kuparuk Industrial Center (KIC) is a multipurpose industrial pad with a freshwater reservoir that has been excavated, leaving a 30 m tall tailings pile adjacent to a well house. This tailings pile generates a large snowdrift on the southwest-facing aspect each winter. We established APD #2 and #3 within this snowdrift and AGD #2 and #3 within the earth surface of the tailings pile.

We surveyed one occupied polar bear den and 2 occupied grizzly bear dens. The polar bear den was under the Big Skookum Bridge in the Endicott subunit of the oilfields. One of the grizzly bear dens was located near the Duck Island mine site, near the Sagavanirktok River and the other was located near the Milne Point intersection, approximately 500 m south of Spine Road (Figure 3.1).

3.4 Methods

3.4.1 Artificial Den Characteristics

We constructed 6 artificial bear dens during October and December 2016 using the same methods and similar dimensions specified by Richard T. Shideler and Craig J. Perham (personal communication, 21 January 2016) in an earlier study (Shideler 2014). All artificial dens were built within 400 m of oilfield infrastructure to ensure that power could be consistently provided to heat sources within dens throughout the winter and so that no buildings or pipelines would obstruct observations of dens. The AGDs were excavated in the soil in late-October, and the entrances were covered with slabs of snow to allow for additional drifted snow to form a snow wall over the entrance and dirt wall (Figure 3.2). Internal den dimensions were measured upon excavation of the dens and verified at the end of the winter monitoring period. The average AGD was 94 cm (SD = 21) long horizontally, 126 cm (SD = 41) wide, and 87 cm (SD = 24) high (Table 3.1). We created APDs in prominent snowdrifts in December and covered entrances with slabs of snow to allow the entrance to fill in with drifted snow to form a wall. The average APD was 137 cm (SD = 41) long horizontally, 153 cm (SD = 46) wide, and 94 cm (SD = 42) high (Table 3.1). We monitored snow wall thickness throughout the denning season by placing a measuring stick through the den entrance wall of AGDs or by inserting a measuring stick through the ceiling wall of APDs. We measured snow wall thickness of artificial dens at the beginning and end of the denning season and during each observation period. Each AGD had a 60 W silicone heating unit, and each APD had a 120 W silicone heating unit, placed on the den floor to mimic temperatures commensurate with the conservatively estimated heat generated by a single grizzly bear or polar bear without cubs. A HOBO Water Temperature Pro v2 Data Logger, or "thermistor" (Onset Computer Corporation, Bourne, MA, USA) was placed securely inside each of the 6 artificial dens to measure interior temperature fluctuations. To measure ambient surface temperature changes over the season, another thermistor was placed outside of each den on the original soil or drift surface and allowed to be covered in snow throughout the winter.

3.4.2 Unmanned Aircraft System and Forward-Looking Infrared Camera Platform

To capture infrared spectrum imagery of the surfaces above artificial bear dens, we selected the FLIR Vue Pro (FLIR Systems, Inc., Wilsonville, OR, USA) 640 × 512 pixel resolution, 30 hz, 19 mm lens 32° × 26° camera based on its UAS specific design and its relatively broad range of IR spectrum sensitivity within the mid-IR (7.5 – 13.5 μm) wavelengths. The majority of our UAS-FLIR imagery was captured using a Ptarmigan Hexacopter (Northern Embedded Solutions, LLC, Fairbanks, AK, USA) fitted with a FLIR Vue Pro camera mounted to a 3-way axis gimbal and Lightbridge (DJI, 2018. Shenzhen, China) communication device to transmit the UAS-FLIR imagery back to the pilot in real time. The Ptarmigan was selected as our aerial platform because of its ability to operate in high wind and cold temperatures, and in accordance with a specifically programed flight plan for a routine and consistent flight pattern. We used Mission Planner (ArduPilot Development Team, 2016) to program the Ptarmigan for a repeat flight pattern at artificial bear den study areas. The Ptarmigan was also an attractive UAS due to its ability to land and take off manually in high wind or other conditions in which automated flight modes were not feasible for safe operation. On 7 March 2017, the Ptarmigan malfunctioned and was no longer operable. We then used a 3DR Solo (3D Robotics, 2009, Berkeley, CA, USA) for the remaining aerial observations through 13 April 2017. We also used the FLIR Vue Pro for all horizontal data collection from a ground level, hand-held position.

3.4.3 Environmental Parameter Data Collection

After collecting UAS-FLIR imagery of the artificial dens, we measured several environmental variables that may affect den detection. Immediately after each observation we measured outside air temperature, ambient snow surface temperature 10 m from the den, and the snow temperature directly above each artificial bear den using a digital thermometer. We also measured den snow wall thickness. We sought to record images before we disturbed the site with measurements to avoid false readings, and thus took measurements after each imaging event. We subtracted ambient snow surface temperature from den snow wall temperature to estimate contrast. We used a Kestrel 1000 (Nielsen-Kellerman, Boothyn, PA, USA) to obtain average wind speed and direction, and maximum wind gust at artificial dens. A Leupold (Leupold and Stevens Inc. 1907, Beaverton, OR, USA) range finder was used to determine optimum vantage points at 100, 50, and 20 m to conduct horizontal observations. Direct sunlight (solar radiation) was categorized as either present or absent. Humidity, barometric pressure, dew point, visibility, and precipitation were recorded from the Kuparuk Airport. Precipitation was categorized as either present or absent.

3.4.4 Sampling Technique

We collected UAS-FLIR imagery at artificial bear dens over 1–3 day trips each month during the denning season, beginning in mid-December 2016 and ending in mid-April 2017. During these sampling periods, imagery was collected during morning civil twilight, daylight, and evening civil twilight, from the vertical and horizontal perspective. Imagery was captured from the vertical perspective using a UAS-FLIR routine flight path that was pre-programmed in Mission Planner according to “ground-truthed” GPS locations of each artificial den. We monitored the live video feed from the UAS-FLIR camera and manually adjusted the angle of the gimbal and the position of the UAS in instances where high winds caused the UAS to hover at an angle to hold position. The UAS was not able to fly at wind speeds exceeding 48 kph, in temperatures below -35°C, or during heavy snow precipitation and thick fog. According to Federal Aviation Association (FAA) regulation, the UAS was not allowed to operate during hours of total darkness, above 122 m above ground level (AGL), or out of the Pilot-in-Command’s line of sight (Dorr 2018).

We were able to opportunistically sample occupied bear dens to assess how the artificial bear dens compared with them. We conducted vertical UAS-FLIR flights over one occupied polar bear den on 21 December 2016 and 15 February 2017, and we collected hand-held UAS-FLIR imagery from the bridge above the den on 11 January and 8 March 2017. We conducted vertical UAS flights over two occupied grizzly bear dens on 15 February 2017 and collected horizontal UAS-FLIR imagery on 8 March 2017. The presence of a polar bear within the den was confirmed when the female and 2 cubs emerged in the spring. The presence of grizzly bears within these dens was verified by radio-collar information, and indication from a scent-trained dog, camera trap imagery, and oilfield personnel observation.

3.4.5 Image Analysis

We conducted 30 UAS-FLIR missions at the KIC and 11 at the DS2M, for a total of 41 UAS-FLIR missions. At the KIC site, our protocols called for sampling the 4 artificial dens from the horizontal and vertical perspective ([4 dens × 30 observation periods] × 3 distances: 20, 50, and 100 m) for a total of 360 possible samples. At the DS2M, our protocols called for sampling the 2 artificial dens from the horizontal and vertical perspective ([2 dens × 11 observation periods] × 3 distances: 20, 50, 100 m) for a total of 66 possible samples. Thus, there were 426 total possible samples from both KIC and DS2M sites. Imagery was initially selected to be included in the analysis based on visual detection in the image, and proper UAS-FLIR positioning. The imagery that we included in the analysis consisted of two possible outcomes: non-detections (correct UAS-FLIR position but no artificial den visible: false negative) and detections (correct UAS-FLIR position with artificial den visible: true positive).

We used Research IR (FLIR Systems, Inc., Wilsonville, OR, USA) software for analysis of the radiometric properties recorded in each image. All the imagery was viewed in “Arctic” palette for best interpretation of temperature differences present in a snow-covered, wind-blown landscape. We applied a pixel equalization algorithm to convert each image to a relative and comparable scale for further post-processing analysis. We uniformly applied the “segment” feature to all images to remove colder pixels from the image until a discrete cluster of the warmest pixels (hot spot) remained that was approximately the size of, or smaller than, a polar bear or grizzly bear den footprint: 1.5 m long by 1.3 m wide (Durner et al. 2003). Using program features, we obtained the pixel count for each hot spot. This allowed us to highlight the size of clustered hot spot pixels and classify them as either detection (1) or non-detection (0). We used median hot spot pixel counts within each subcategory (e.g., APD, vertical, 20 m; Table 3.2) and classified detections at or below the median as non-detections to distinguish detections with quantifiable characteristics of visible detection.

We used a logistic regression model (Hosmer and Lemeshow 2000) to predict den detection (dependent variable: 0 or 1 categorized using size of den hot spot) based on environmental variables (independent variables; n = 11) recorded at the time of observation. We excluded variables that would be unknown when attempting to detect an occupied bear den, such as den snow wall thickness and snow surface temperature directly above the den. We performed a correlation and factor analysis in order to group similar environmental variables, simplify our dataset, and avoid problems of multicollinearity in regression analysis. From within highly correlated groups, we selected one predictor variable for inclusion in our model based on importance in previous research (Amstrup et al. 2004, Robinson et al. 2014), interpretability, and representation of other variables in the group. We tested for multicollinearity using the variance inflation factor (VIF) score, where a VIF score ≥ 4.0 is considered to be collinear (O'Brien 2007). We also tested for multicollinearity using the Spearman's rank correlation matrix, and removed less interpretable variables from each highly correlated ($r_s > 0.6$) grouping (Zar 1971). We conducted a logistic regression on all imagery within our four UAS-FLIR observation categories: AGD vertical, AGD horizontal, APD vertical, and APD horizontal. All analyses were performed using IBM SPSS (IBM Corporation, 2015, V23). The following known environmental variables were considered predictors in the logistic regression models: air temperature, humidity, dew point, temperature dew point spread, barometric pressure, solar radiation, wind speed, wind gust speed, cloud cover, visibility, and precipitation. Predictors were excluded from the model if there was insufficient variation within the sample for our model to converge. We interpreted the results of the logistic regression model by considering any continuous or categorical predictor variable with $p \leq 0.09$ as significant and used the beta coefficients to obtain the odds ratio. We estimated the effect that a 1-unit change, or 1-category change in predictor variable, would have on the odds that a detection (1) will occur instead of a non-detection (0). We compared month with ambient air temperature and den wall thickness for AGD and APD using a Kruskal-Wallis test to evaluate the strength of the relationship. To test the effect of distance on odds of detection, we compared predicted hot spot pixel count decline with actual hot spot pixel count decline. Because an image captured at 50 m is 60% ([20 ÷ 50] - 1 = 0.6) further from the den than an image captured at 20 m, the hot spot pixel count at 50 m would be expected to contain 60% fewer pixels in the hot spot pixel count than an image captured at 20 m, and the predicted hot spot pixel count at 100 m would be 50% smaller than that of the hot spot pixel count at 50 m.

3.5 Results

3.5.1 Descriptive Statistics of FLIR Images

We were successful in capturing and identifying 291images of the artificial dens for inclusion in our analysis for a 68% success rate. The images were distributed as follows: AGD vertical (n = 52), AGD horizontal (n = 78), APD vertical (n = 81), and APD horizontal (n = 80). We classified 41% as detections (n = 119) and 59% as non-detection (n = 172) (Table 3.2). Artificial polar bear den images comprised 55% of observations (n = 161), and AGD comprised 45% of observations (n = 130); 54% of images were taken from the horizontal perspective (n = 158) and 46% were taken from the vertical perspective (n = 133). The results suggested that median detection pixel counts from the vertical perspective were more than four times greater than that of detections from the horizontal perspective, and median APD detection pixel counts were more than five times greater than that of AGD detections. Median APD detection pixel counts were approximately two times greater than that of AGD detections at both the horizontal and vertical perspectives (Figure 3.3, Figure 3.4). The 20- to 50-m hot-spot pixel count decline for AGD and APD vertical imagery decreased by a third and a half of expected decline, respectively, and 50- to 100-m hot spots were close to expected pixel count decline. The 20- to 50-m declines for horizontal imagery were close to expected, with APD showing a third less than expected decline; 50 to 100 m declines were greater than expected (Table 3.2).

3.5.2 Environmental and Artificial Den Characteristics

In the 12 days of artificial den observations that occurred over the 5-month study period, we collected 41 measurements of the 11 "known" weather conditions (Appendix A) and "unknown" physical den characteristics. Most measurements were made in the absence of solar radiation (n = 32). Ambient air temperature during the sample period ranged between -9°C and -29°C. Wind speed ranged between 6 kph and 37 kph. Over half of our observations (n = 21) took place in the absence of precipitation. The snow wall thickness over the den entrance of AGDs measured a minimum of 15 cm in December and a maximum of 150 cm in April. The snow wall thickness above the den of APDs measured a minimum of 1 cm in December and a maximum of 57 cm in April (Table 3.1).

The maximum temperature inside the AGDs was -2.2°C and the minimum temperature inside the AGDs was -7.5°C; the maximum temperature inside the APDs was -1°C and the minimum temperature was -4.3°C. The average den snow wall surface temperature for AGDs measured -11.9°C (SD = 8.4), which was 6.2°C warmer than average surrounding ambient snow temperature (-18.1°C, SD = 8.3). The average snow wall surface temperature of the APDs measured -10.1°C (SD = 6.9), which was 8.0°C warmer than average ambient snow surface temperature surrounding the APDs (-18.1°C; SD = 8.3). Upon retrieval of the thermistor inside APD #3, we found that the thermistor was compromised, and it was not possible to upload the temperature information from this artificial den. All other thermistors and recorded temperature data were successfully recovered.

3.5.3 Effects of Environmental Conditions

The factor reduction analysis indicated that 4 underlying environmental variables explained most (81%) of the variance observed in the 11 known environmental variables recorded with each den image. Air temperature was highly correlated ($r_s > 0.6$) with humidity, dew point, and temperature-dew point spread. We included air temperature in our final models and excluded predictors that explained the same variation. We included solar radiation in our final models instead of cloud cover as an explanatory variable because they were highly correlated ($r_s > 0.6$) and solar radiation was considered important in previous studies. During daylight hours with full cloud cover, solar radiation was absent. There was not enough variability in solar radiation or cloud cover for AGD horizontal, and it was not possible to include in this model. Wind speed was highly correlated ($r_s > 0.6$) with wind gust speed and barometric pressure. We included wind speed in the final models because of its importance in previous studies. We included precipitation over visibility in the final models because it was highly correlated ($r_s > 0.6$) and because precipitation measured the presence of suspended atmospheric moisture from both the horizontal and vertical perspectives, an important predictor in previous studies.

For the AGD horizontal model, an increase of 1°C ambient air temperature lowered the odds of detection by 8% ($p = 0.05$, Table 3.3), and an increase of 1 kph in wind speed raised the odds of detection by 18% ($p = 0.08$). There was insufficient variability in solar radiation to measure the effect on AGDs from the horizontal perspective. For AGD vertical, none of the predictors were significant at the $p \leq 0.09$ level. For APD horizontal, an increase of 1°C in ambient air temperature lowered the odds of detection by 10% ($p < 0.01$), and the presence of precipitation lowered the odds of detection 10-fold ($p = 0.06$). For APD vertical, an increase of 1°C in ambient air temperature lowered the odds of detection by 12% ($p < 0.01$), an increase of 1 kph in wind speed lowered the odds of detection by 5% ($p = 0.1$), the presence of precipitation lowered the odds of detection by 5.6 times ($p = 0.03$), and the presence of solar radiation lowered the odds of detection by 4.3 times ($p = 0.05$). The Kruskal-Wallis test indicated that ambient air temperature increased each month ($p = 0.09$) and that den wall thickness increased each month for both AGDs and APDs ($p < 0.01$).

3.6 Discussion

Air temperature is the variable that best predicts UAS-FLIR den detection for APDs and AGDs within 100 m at the horizontal perspective, and APDs from the vertical perspective. As ambient air temperature decreases, the odds of detection increases because of (1) colder ambient air temperatures causing an increased contrast between den snow wall surface temperature and surrounding ambient snow temperature, (2) the tendency for colder temperatures to be associated with clear, dry conditions, (3) warming outside air temperatures later in the winter season when den walls are thickest and most insulating, and (4) warmer outside air temperatures later in the winter season when there are longer periods of daylight and increased absorption of solar radiation from landscape features that then emit heat and obscure the UAS-FLIR sensor's ability to detect and distinguish the artificial den from other hot spots. As FLIR systems measure relative differences in surface temperatures, colder ambient air temperatures increase the differential between exterior and interior den air temperature. This draws internal warm air through the snow wall over the top (APDs), or through the den entrance (AGDs), which increases the contrast between ambient snow surface temperatures and den snow wall surface temperatures.

The high correlation between air temperature and humidity, dew point, and temperature-dew point spread may also explain the influence that air temperature had on odds of den detection. Amstrup et al. (2004) observed that a 1°C increase in temperature-dew point spread increased the odds of detecting an occupied polar bear den by over 3 times, whereas the presence of airborne moisture reduced the odds by almost 5 times. Amstrup et al. (2004) suggested that this was due to atmospheric moisture interfering with the FLIR sensor's ability to discriminate IR wavelengths at the surface. As distance between the UAS-FLIR and the den increases, more particulate is suspended in the air between the sensor and the den, and thus the UAS-FLIR is measuring the temperature of the atmospheric particulate rather than the den. The presence of precipitation (falling or suspended moisture) decreased the odds of den detection for APDs in our study more than Amstrup et al. (2004), and this effect is expected to have an even greater influence on odds of detection as distance increases for UAS-FLIR imagery and perhaps that of hand-held and aerial systems. Colder air temperatures were associated with the clear, dry conditions that we found to be optimal for UAS-FLIR based den detection.

Solar radiation (i.e., direct sunlight) was shown to have a negative effect on the ability of FLIR cameras to detect both occupied (vertical perspective only) and artificial (horizontal perspective only) polar bear dens (Amstrup et al. 2004, Robinson et al. 2014). Solar radiation decreased the odds of detection for APDs at the vertical perspective, but was not influential on the odds of detection for any of the other models. Solar radiation is expected to reduce the FLIR camera's ability to measure contrast between ambient snow temperature and den snow wall surface temperature due to solar reflectance from the snow surface interfering with the FLIR camera's ability to distinguish fine-scale temperature differentials. This interference would lead to lower hot spot pixel counts and to a categorization of non-detection, or 0, in our study. Because Amstrup et al. (2004) and Robinson et al. (2014) recommended avoiding surveying during hours of direct sunlight, we collected samples primarily during hours of civil twilight, both morning and evening, to eliminate solar radiation as a variable and test for the effects of other weather conditions. This is partially why our sample size of observation periods with the presence of solar radiation is low (n = 9). Even with a low sample size, one effect that solar radiation had on our odds of detection was an increase in false positives due to the presence of exposed tundra or other "black bodies" in the vicinity of the artificial bear dens that were absorbing solar radiation and emitting heat. Without prior knowledge of the location of the artificial dens from the vertical perspective, some imagery was difficult to interpret due to numerous false positives associated with exposed ground that had absorbed, and was emitting, solar heat. From the horizontal perspective, the effect of solar radiation did increase false positives, but it also increased false negatives as the result of imagery becoming so distorted in relative scale that no den would be possible to observe due to either direct sunlight facing the UAS-FLIR or the reflectance in the background of the image.

High wind speed was indicated as an important predictor variable that had a negative effect on odds of detection by Robinson et al. (2014), and it was also considered to have a negative effect by Amstrup et al. (2004), due to the effect of rolling and suspended snow particles on the FLIR sensor's ability to measure snow surface temperature differentials. In our study, increased wind speed decreased the odds of detection for APDs from both the horizontal and vertical perspective, but most significantly from the vertical perspective ($p = 0.1$). Amstrup et al. (2004) noted that a mean wind speed on days when they did not see occupied polar bear dens (20 kph) was significantly higher than the mean wind speed (11 kph) on days when they did see polar bear dens. Wind speeds exceeded 20 kph for 73% ($n = 30$) of our samples. We expected that the den hot spot would be obscured from the UAS-FLIR at wind speeds high enough to cause the rolling of snow particles along the snow surface. This could occur at wind speeds as low as 15 kph, depending on the bonding of the snowpack and snow grains (Li and Pomeroy 1997). Considering that 83% ($n = 34$) of our samples took place in wind speeds exceeding 15 kph, it is possible that we did not sample in low enough wind speeds to measure the threshold at which wind speed begins to significantly affect the odds of detection for APDs.

An increase in wind speed did cause the imagery to appear less focused and also increased the presence of false positives, but these were easy to distinguish from the surrounding environment due to their elongated and linear formation. Prominent landscape features with discrete edges such as small wind drifts and areas of exposed tundra were more difficult to discern from artificial dens because they generated friction and heat in a discrete location and had a relatively warm appearance as compared with the surrounding environment in the UAS-FLIR imagery. This effect can be seen in AGDs: odds of detection increased with greater wind speed, likely due to the protruding dirt features associated with AGD #1 and #2 that would generate measurable wind friction over the den snow and dirt wall allowing us to acquire a small hot-spot pixel count over a known AGD location. These pixel counts were very small, and if the location of the AGD den location was not known, these images would be considered to be false negatives. This effect was also evident in UAS-FLIR imagery of an occupied grizzly bear den that was established in a 2 m tall bank of tundra and had a large dirt tailings pile outside of the den entrance from excavation. We conducted observations of this from both the vertical and the horizontal perspectives, and we observed no sign of a hot spot over the den snow wall entrance. We did observe a hot spot generated by the presence of the prominent tailings pile outside of the den, which was absorbing heat from the sun and presumably generating friction from the wind. This feature could be measured using the hot spot pixel count, but was in fact a false positive. This result is spurious and indicates that UAS-FLIR may not be a reliable method for detecting occupied grizzly bear dens.

The negative relationship that odds of den detection had with den snow wall thickness is intuitive, and its significance is representative of two things: (1) contrast between ambient snow temperature and den snow wall temperature decreased as den snow wall thickness increased, and (2) AGD #3 accumulated a 125 cm snow wall over the den entrance by 6 March 2017, after which there was no measurable temperature contrast between ambient snow and den snow wall surface, making it no longer visible with the UAS-FLIR. Robinson et al. (2014) found that a 1-cm increase in den snow-wall thickness increased odds by 1.49 of an artificial polar bear den being undetectable from the horizontal perspective, with a mean den snow-wall thickness of 90 cm. In our study, an increase in den snow-wall thickness reduced odds of detection for all artificial dens, but only AGD #3 exceeded a den snow wall thickness of 80 cm. Our sampling technique was not at a sufficiently fine scale to observe a critical threshold at which den wall thickness affected odds of detection, but we observed that it occurred in an interval of 80 and 125 cm for AGD #3. The positive relationship between an increase in snow-wall thickness and month implies that it is best to conduct UAS-FLIR surveys early in the winter, before large-scale snow events and subsequent drifting snow, when snow walls are at their thinnest. The positive relationship between air temperature and wall thickness is due to spring conditions, when walls are thickest and temperatures are warmer, resulting in a decrease in contrast between the temperature of ambient snow and snow wall surface temperatures. Wall thickness increased throughout the winter season in all dens, reaching its maximum in April, when ambient air temperatures were relatively warm compared with temperatures in early or mid-winter. The increased snow-wall thickness reduced the presence of surface heat available for the UAS-FLIR sensor to measure. Artificial grizzly bear den #3 is a good example. Although the den was detected earlier in the season, by March the depth reached 125 cm and the den could no longer be detected.

Part of the reason that AGD detections had fewer pixels in their hot spot than that of APD detections is explained by the difference in artificial den composition. The AGDs were constructed to simulate a real den by digging horizontally into a sloped earth surface to create a large dirt cavity that retained a dirt wall above the cavity. Dirt and other materials that grizzly bears den within are denser than snow and provide more insulation over the top of each AGD compared with APDs that were excavated from existing snowdrifts leaving only a snow wall above the cavity. The denser AGD dirt walls prevented heat from escaping through the top of the den and resulted in reduced contrast in heat differentials visible to the UAS-FLIR directly over AGDs, creating a visible hot spot as heat escaped through the snow-covered den entrance instead. Artificial polar bear dens were 1.9 times larger than AGDs and were equipped with twice the heat output to account for a polar bear's larger body size. When comparing watts/cm^3, the heat output for AGDs and APDs were both equal to 0.00006 watts/cm^3.

Throughout the sampling period, the average temperature inside of the AGDs was 13.8°C warmer than ambient outside air, whereas the average temperature inside of the APDs was 15.7°C warmer than ambient outside air, with the greatest temperature contrast between inside and outside air occurring at colder ambient air temperatures (Table 3.1). Both APDs and AGDs maintained interior temperatures within the range of occupied bear dens (Watts 1983, 1990), and APDs remained 1.8°C warmer than AGDs. As in the case of AGD #3, the contrast between den interior temperatures and outside air temperatures can be large if the den is well-insulated and no heat is able to escape, but the UAS-FLIR detects snow surface temperature differentials, so detections of well-insulated dens can be poor if snow surface temperature contrast is low. Snow-wall surface temperature over the den entrance to the AGDs averaged -11.9°C (SD = 8.4), and snow-wall surface temperatures over the top of APDs averaged -10.1°C (SD = 6.9), confirming that the heat being emitted through the snow-wall surface above the AGD entrance was 1.8°C less than the heat being emitted through the snow-wall surface above the APDs, despite equal heat output. This difference suggests that AGDs are better insulated from ambient outside air temperatures than APDs and that the temperature difference in den snow wall temperature contributed to the smaller hot-spot pixel count. The UAS-FLIR imagery also shows how AGDs transfer heat differently to the surrounding environment than APDs. The AGDs transfer heat through the entrance of the den, whereas the APDs transfer heat directly through the top of the den. This difference can be seen by looking at the hot-spot shape and location from the vertical perspective (Figure 3.4). The shape of the visible den indicates the pattern of heat distribution as it escapes from the interior cavity, and the location of the hot spot indicates the location from which heat is escaping. The APDs appear as circular "lightbulbs" over the top of the cavity compared with the more variable shapes associated with the den entrances of AGDs. This shape differential was not observed when comparing UAS-FLIR detections of occupied grizzly bear and polar bear dens in our study, but our sample size of occupied den imagery was small.

Given that we know the smaller dimensions and the additional soil substrate and snow depth of AGDs, and the fact that den entrances are adjacent to the main den cavity and not above it, it is not surprising that their median hot-spot pixel count was smaller and more discrete than that of APDs, but the real-world implications of this result are significant to understanding the efficacy of using UAS-FLIR for detecting grizzly bear dens. If our AGDs accurately represented the variation in grizzly bear den morphology, the size and shape of visible AGD hot spots imply that UAS-FLIR grizzly bear den detection surveys will be difficult to perform effectively for several reasons. First, if grizzly bear dens produce small hot spots, they may not be readily visible to the observer, resulting in false negatives. Second, the small size and variable shape of the grizzly bear den hot spot will make grizzly bear dens more difficult to distinguish from other landscape features that absorb solar radiation or generate wind friction, increasing the chances of both false negatives and false positives. The known variation in physical den characteristics introduces a level of uncertainty regarding whether a grizzly bear den is possible to reliably detect using UAS-FLIR imagery. In the case of AGD #3, the depth of the 1.5 m dirt wall combined with the 125 cm snow wall that had accumulated by early-March resulted in a virtually undetectable den at that time of year. Artificial grizzly bear den #3 maintained an average interior temperature of 6.2°C warmer than AGD #1 and #2; however, the surface temperature was indistinguishable from the surrounding snow temperatures after the snow wall over the den entrance reached a depth of 125 cm. With no heat differential present in the snow surface covering the entrance to AGD #3, a UAS-FLIR den detection survey will no longer be effective. Prior to the development of a > 80 cm snow wall, AGD #3 was possible to detect using UAS-FLIR. This has implications for timing of bear detection surveys using this technology.

The vertical perspective yielded better detections than the horizontal perspective from every distance, for both AGDs and APDs (Figure 3.2, Figure 3.3). Detections from the vertical perspective produced circular hot spots that were easily distinguishable from the surrounding landscape features. Detections from the horizontal perspective could be distinguished from the surrounding landscape, but the hot spot would be elongated more like a "heat horizon" rather than the "lightbulb" appearance of vertical detections. For APDs, the heat from the den dissipates through the snow wall above the cavity in a circular formation, with the warmest pixels in the middle and the heat gradually fading at the edges (Figure 3.5). This circular shape stands out from its surroundings when viewed from the vertical perspective, but when viewed horizontally, the shape of the den appears oblong and tends to blend in with other landscape features that also run horizontally (e.g., drifted snow features, land horizons). The AGDs also appeared as a "lightbulb" in good conditions, with the warmest pixels located over the snow wall covering the den entrance. This produced a hot spot with a hard, contrasting border over the dirt wall and a smooth temperature gradient on the side with only a snow wall. Both APD and AGD hot spots were not easily visible when viewed from a horizontal perspective if the orientation was not perpendicular to the AGD den entrance.

The less-than-expected hot-spot pixel count decline for APD and AGD between 20 and 50 m from the horizontal and vertical perspective indicates that weather may have a reduced effect on odds of detection for UAS-FLIR at $\leq$ 50 m distance, and that air temperature, wind speed, precipitation, and solar radiation begin to affect hot-spot pixel count numbers between 50 and 100 m. We expect that this would also be the case with occupied grizzly bear and polar bear dens, considering that our data on artificial dens approximate measurements of occupied dens. This result quantifies a phenomenon that we observed when we captured den imagery from approximately 2 m when standing directly over the den to collect observations. From a close distance, both APDs and AGDs did not stand out from the surrounding snow surface due to a lack of relative temperature differentials within the UAS-FLIR camera's sensor coverage. If the hot-spot footprint fills the entire image, the UAS-FLIR camera will measure temperature differentials from entirely within that hot spot, and no discrete cluster of warm pixels can be distinguished from the surrounding ambient snow surface temperature. The artificial den hot spot is clearly visible from 20 m, occupying as much as 0.43% of image pixels. The artificial dens are clearly visible from 50 m, and no interference from weather conditions is apparent from either the horizontal or vertical perspective. The hot-spot pixel count is greater than the expected hot-spot pixel count decline at 50 m, indicating that the UAS-FLIR camera may be more effective at this distance than at 20 m, due to an increase in contrast between measured ambient snow pixel temperature and artificial den snow surface pixel temperature within the UAS-FLIR camera's sensor coverage. The dens can be differentiated from the surrounding environment at 100 m with minimal interference from weather conditions, and we see that the hot-spot pixel count is closer to the expected hot-spot pixel count decline at this distance. This result also implies that optimal survey distance for UAS-FLIR surveys resides between 50 and 100 m: a distance that is close enough for den detection to occur without interference from weather conditions, but far enough away for a maximum sensor swath (46 × 35 m at 100 m) coverage per image.

We collected UAS-FLIR observations of the occupied polar bear den from the vertical and hand-held perspective once per month between December 2016 and March 2017 (Figure 3.6). Observations from the hand-held perspective were captured from the 45-degree perspective due to regulatory limitations that prevented us from capturing horizontal imagery (the polar bear was denned under a bridge and we were not allowed to go under or around the bridge). The den was possible to detect with the UAS-FLIR until March, at which point a substantial accumulation of drifted snow had formed over the den and an IR signal was no longer visible. Our sample size of occupied dens was not large enough to compare with results of our artificial den study, but we were able to verify our "proof-of-concept" by capturing UAS-FLIR imagery of an occupied polar bear den. Considering that samples were collected at distances between 10 and 50 m, we would not expect weather to have had much effect on odds of detection within this range. In our study, given the small hot-spot pixel counts in the imagery of the one occupied polar bear den, we expect that it could be challenging for experts in this field to reliably detect an unknown, occupied polar bear den using UAS-FLIR systems alone, even early in the denning season. Our APDs were approximately representative of an occupied polar bear den and they were almost always detectable, even in poor conditions, using UAS-FLIR indicating that a greater sample size of occupied polar bear dens is needed to define parameters in order to make this technique more successful.

We also collected observations of two occupied grizzly bear dens on two separate occasions in February and March. We captured UAS-FLIR imagery from both the horizontal and vertical perspective to verify our "proof-of-concept." One den was clearly visible from the vertical perspective (Figure 3.7), but difficult to discern when viewed from the horizontal perspective. The other den was not detected from either perspective, on either of the two sampling occasions. The fact that a grizzly bear den was possible to detect with such certainty from the UAS-FLIR was a significant accomplishment of our study, but the inability of another grizzly bear den to be detected under similar conditions calls into question the effectiveness of this technique for broad application. Note that the detectable grizzly bear den was occupied by a female and two cubs that were observed to emerge later that spring. The clearly visible hot spot is above the entrance to the den, which had recently been disturbed by trained scent-dog indication (Figure 3.7). Before the surface of the den entrance was disturbed, the UAS-FLIR detected a poorly defined hot spot (Figure 3.8). The occupied grizzly bear den that was not detectable was located using reported sightings and trained scent-dog indication. A single bear emerged from this den location later that spring. Otherwise, the den morphology appeared similar in that each bear had established a den within a small 1.5–2 m tall change in topography. Thus, it may be that dens occupied by family groups, or specifically lactating females with cubs, are more detectable than those occupied by single bears.

3.7 Management Implications

Our study indicates that air temperature, wind speed, and presence or absence of precipitation and solar radiation can be used to predict odds of detection for artificial bear dens from both the vertical and horizontal perspectives, at ≤ 100 m distance, early in the winter season. We also found that vertical imagery produced better detection qualities than detection qualities of horizontal imagery. Given that our artificial dens were representative of the physical characteristics of occupied polar bear and grizzly bear dens, and that we sampled our artificial dens in environmental conditions representative of those present in bear den habitat of arctic Alaska, we expect that our results will also apply to UAS-FLIR surveys of occupied bear dens. We recommend that (1) FLIR-mounted UAS platforms be added to the game-management toolbox to enhance the effectiveness of managers and field personnel surveying or monitoring arctic bear dens, and (2) UAS-FLIR surveys should be conducted in cold, clear conditions with calm winds (< 15 kph) at night or during civil twilight in November (grizzly bear) and December or January (polar bear) before den wall thickness affects odds of detection. Our results indicate that UAS-FLIR imagery can be effective in detecting grizzly bear dens, but variation in den morphology and occupancy, as well as the effects of solar radiation and changing wind speed will limit predictable UAS-FLIR den detection from both the vertical and horizontal perspectives at $\geq$ 100 m. Air temperature and snow wall thickness over AGD entrances were the only predictors that influenced the odds of UAS-FLIR den detection, and we observed that the vertical perspective yielded better results than the horizontal perspective. Increased wind speed raised the odds of detection for AGDs from the horizontal perspective, but this should be considered a failure of the technique, in that the heat generated by wind friction produced a measurable false positive associated with the prominent dirt features that AGD #1 and #2 were established within.

We did not test but rather demonstrated the practical application of UAS-FLIR for detecting occupied bear dens. Current systems are limited by the effect that cold temperatures have on UAS battery power, the effect that high winds have on the ability of the UAS to maintain stable flight, their inability to operate during periods of high wind and/or precipitation, and FAA regulations that prohibit flight during night-time hours, at altitudes exceeding 122 m AGL, and at distances that are out of the Pilot-in-Command's line of sight (Dorr 2018). Our study indicates that more advanced UAS-FLIR cameras with simultaneous visual and infrared spectrum imagery collection will help experts distinguish true positives from false positives in UAS-FLIR imagery, and that modern "Arctic-grade" UASs, with exemptions to current FAA regulations, could overcome limitations of current platform restrictions. Whether surveys are conducted using UAS or manned aerial vehicles, the effectiveness of FLIR systems for locating bear dens is still limited by weather conditions, by the unknown physical characteristics of the den, and by the ability of experts in this field to use visual elements of interpretation to classify detections and non-detections. It is possible that future analysis of FLIR imagery may lead to the establishment of an algorithm that could identify imagery containing true positives and false positives as a means of filtering the imagery in preparation for classification by expert opinion, but it is unlikely that any form of post-processing technique will be able to eliminate the occurrence of false negatives without some form of prior knowledge of bear den location.

The occurrence of false negatives presents the greatest management concern for both bear conservation and worker safety. Therefore, for practical applications in which industry is required to locate and avoid bear dens prior to winter exploration and expansion activities, we recommend that UAS-FLIR surveys be coupled with secondary methods, such as repeat surveys or the application of trained scent dogs, to reduce the occurrence of false negatives. For research purposes, putative den sites indicated by any method should also be confirmed by ground-based, snow-free verification surveys or camera trap systems to confirm that the location of the detection constitutes a true positive. Snow-free confirmation will allow researchers to further understand the success rate of these den-detection techniques. In our opinion, this methodology presents a powerful tool for arctic bear den detection that will enhance worker safety and bear conservation on the North Slope oilfields of Alaska, with broad application throughout the north, but further research and development of this methodology are required.

3.8 References

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3.9 Figures

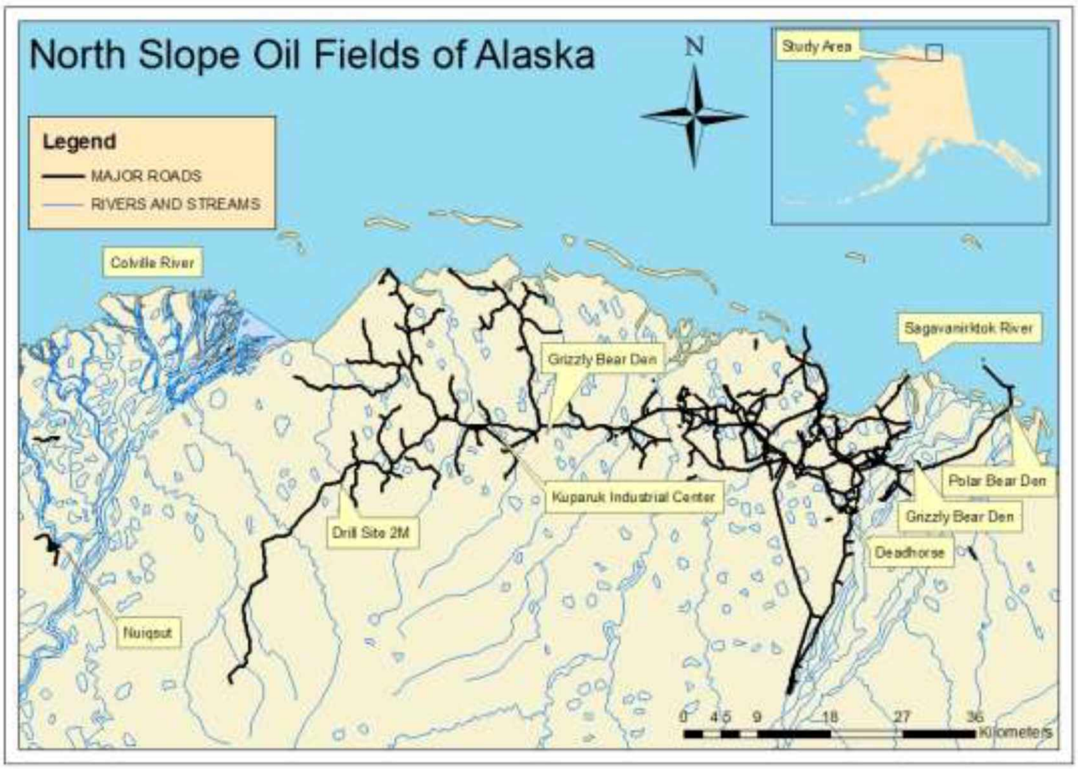


Figure 3.1. Study area: North Slope oilfields of Alaska (USA). Artificial grizzly bear and polar bear dens #1 located at Drill Site 2M and artificial grizzly bear and polar bear dens #2 and #3 located at the Kuparuk Industrial Center. The location of the occupied polar bear den and two grizzly bear dens are labeled.

Figure 3.2. Infographic depicting our artificial polar bear and grizzly bear den characteristics and survey methodology using unmanned aircraft systems hovering above the dens to capture forward-looking infrared imagery of heat emanating from artificial den snow wall surfaces in the North Slope oilfields of Alaska (USA).

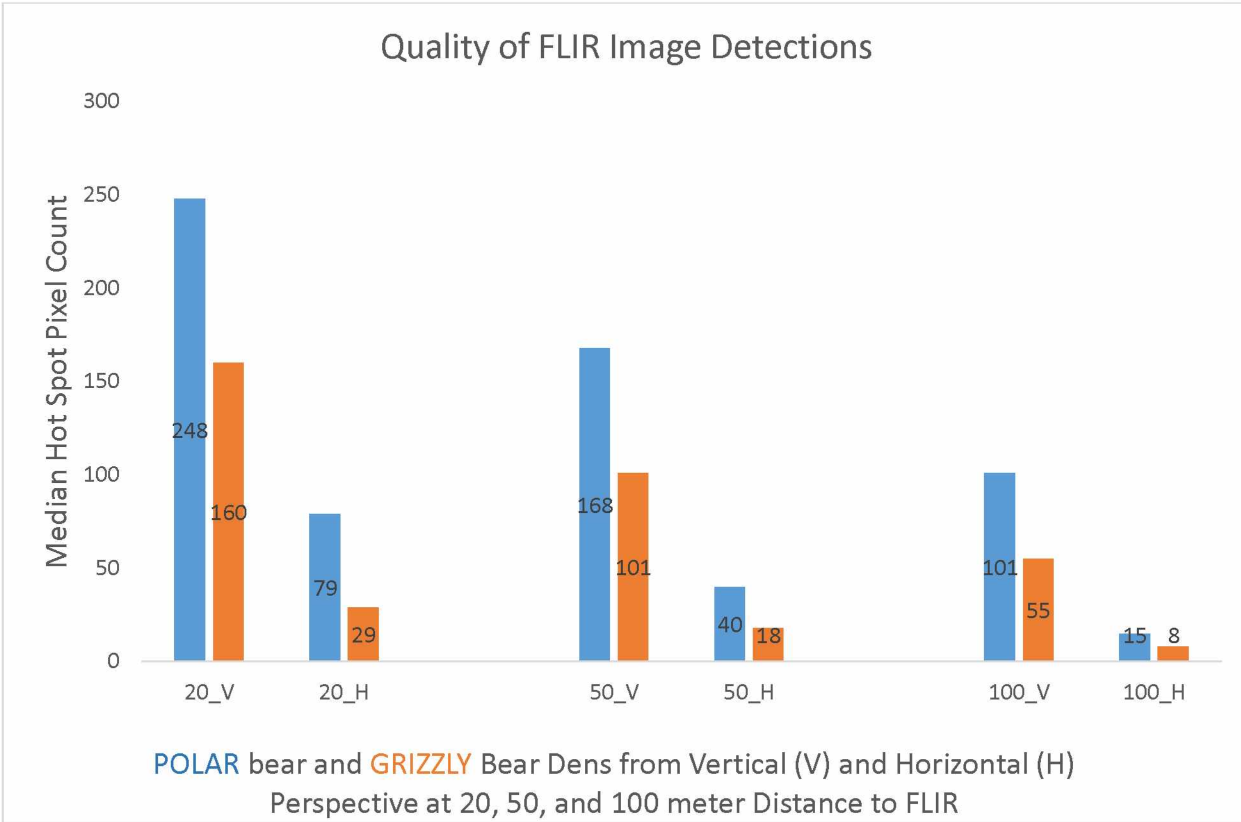
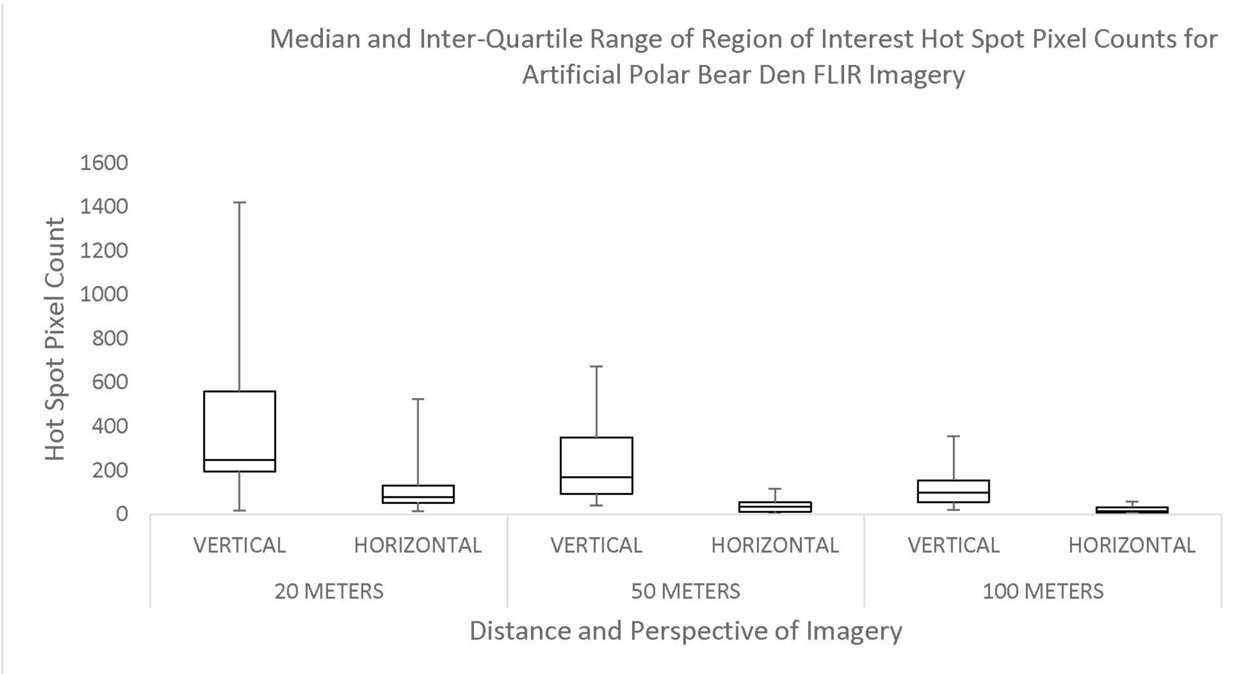


Figure 3.3. Median hot spot pixel count for forward-looking infrared imagery of artificial polar bear and grizzly bear dens from the horizontal and vertical perspective, at 20, 50, and 100 m distance in the North Slope oilfields of Alaska (USA).



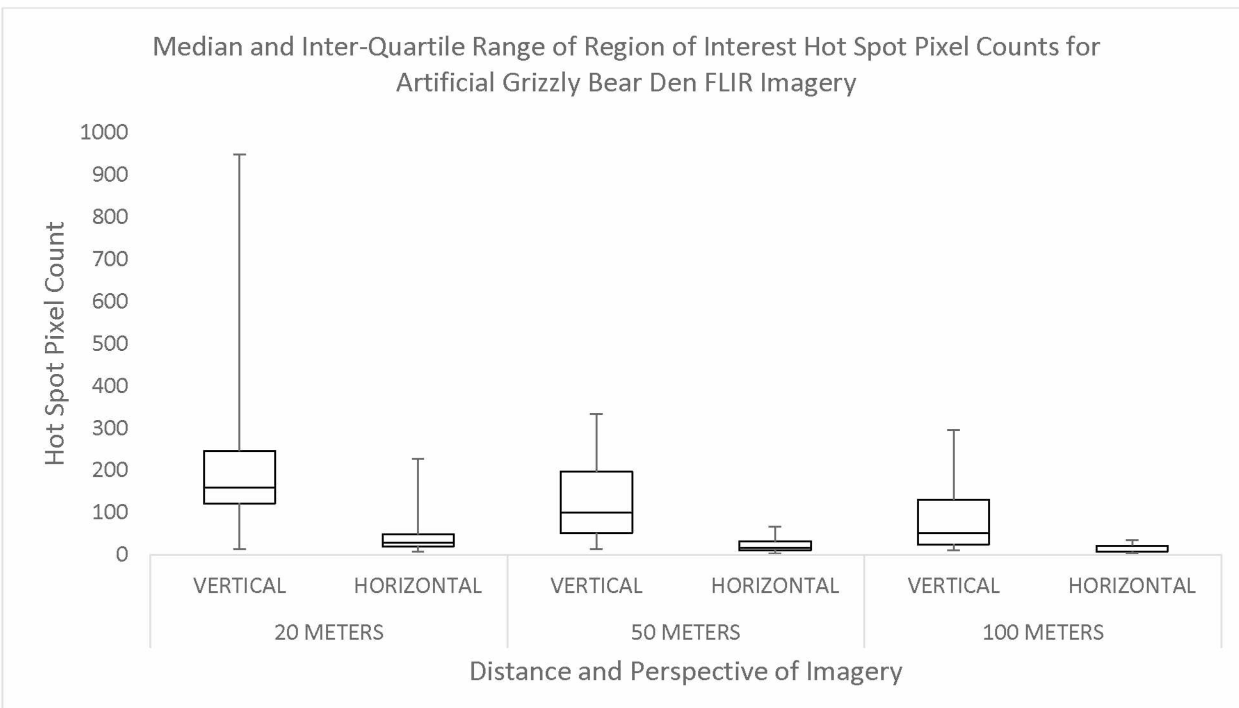
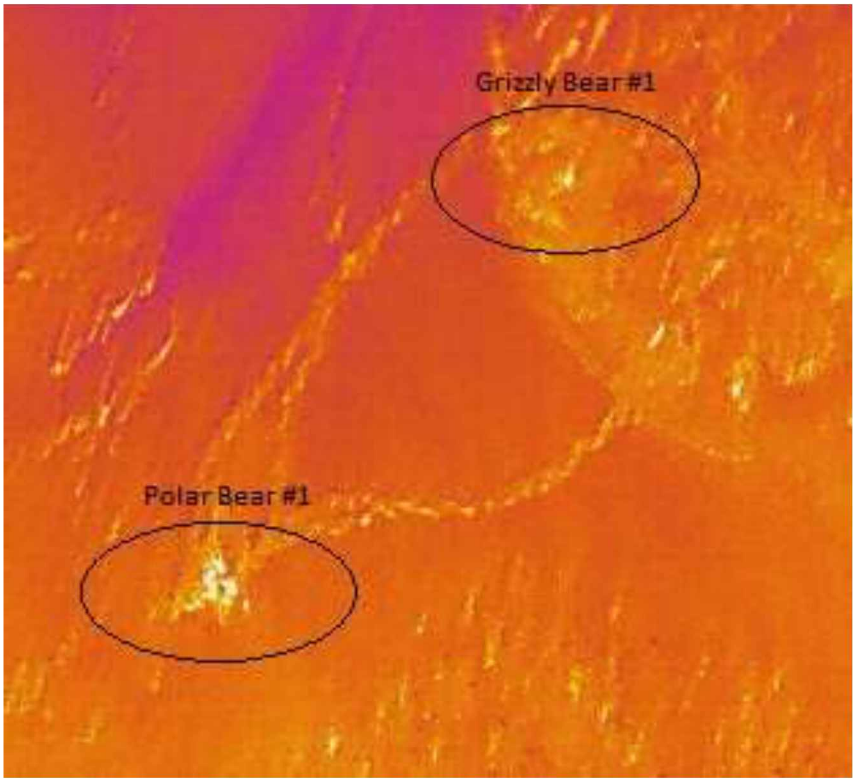


Figure 3.4. Hot spot pixel counts for artificial polar bear and grizzly bear den imagery captured with forward-looking infrared (FLIR) camera from a distance of 20, 50, and 100 m, at a vertical and horizontal perspective, in the North Slope oilfields of Alaska (USA). Hot spot pixel count represents the quality of detections relative to the distance and perspective of the FLIR image.



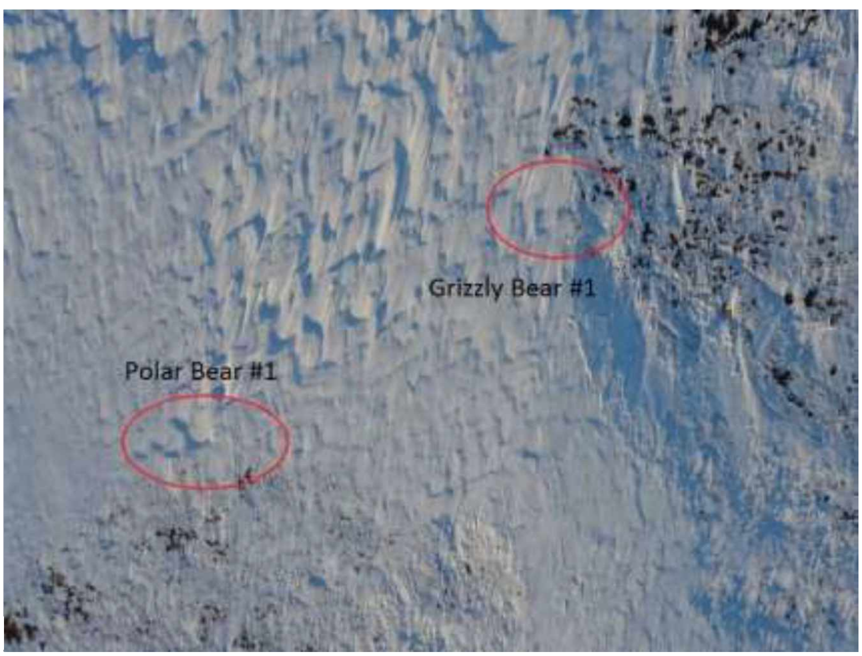
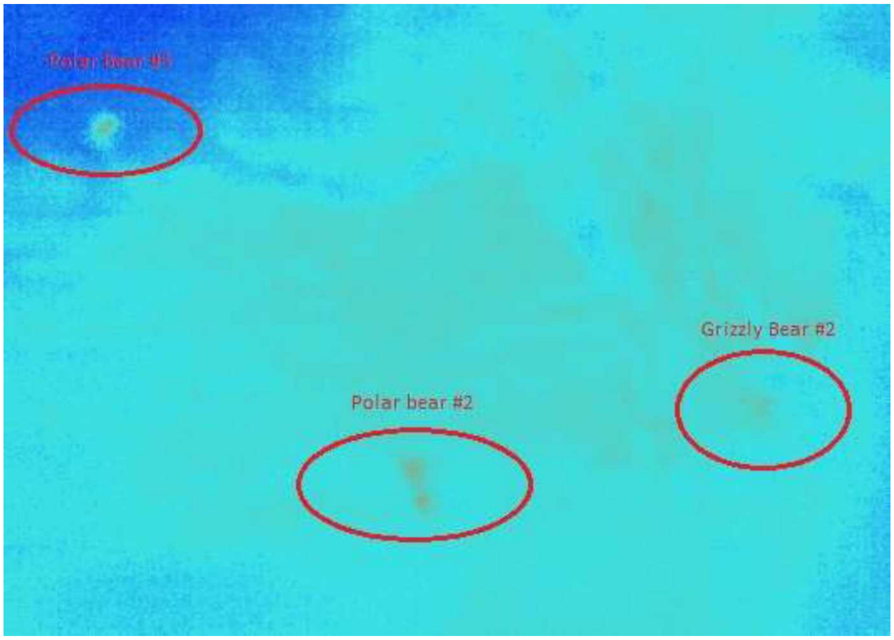


Figure 3.5A. Vertical imagery of artificial dens at Drill Site 2M in the visible and infrared spectrum from a distance of 100 m in the North Slope oilfields of Alaska (USA).



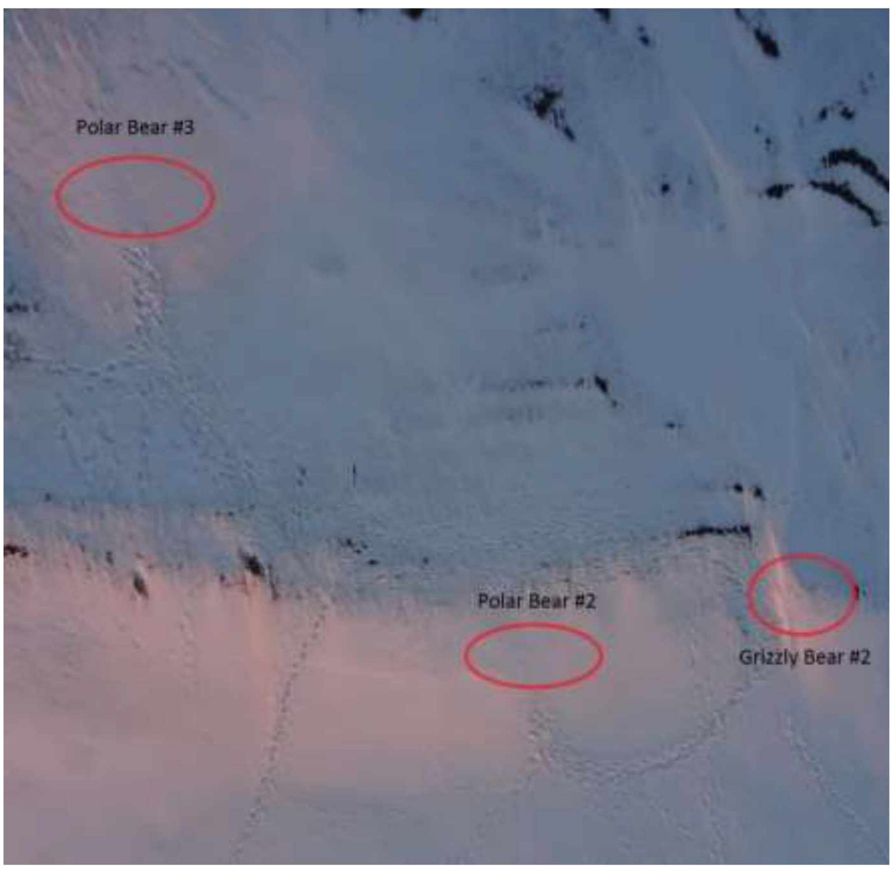


Figure 3.5.B. Vertical imagery of artificial bear dens at Kuparuk Industrial Center in the visible and infrared spectrum from a distance of 100 m in the North Slope oilfields of Alaska (USA).

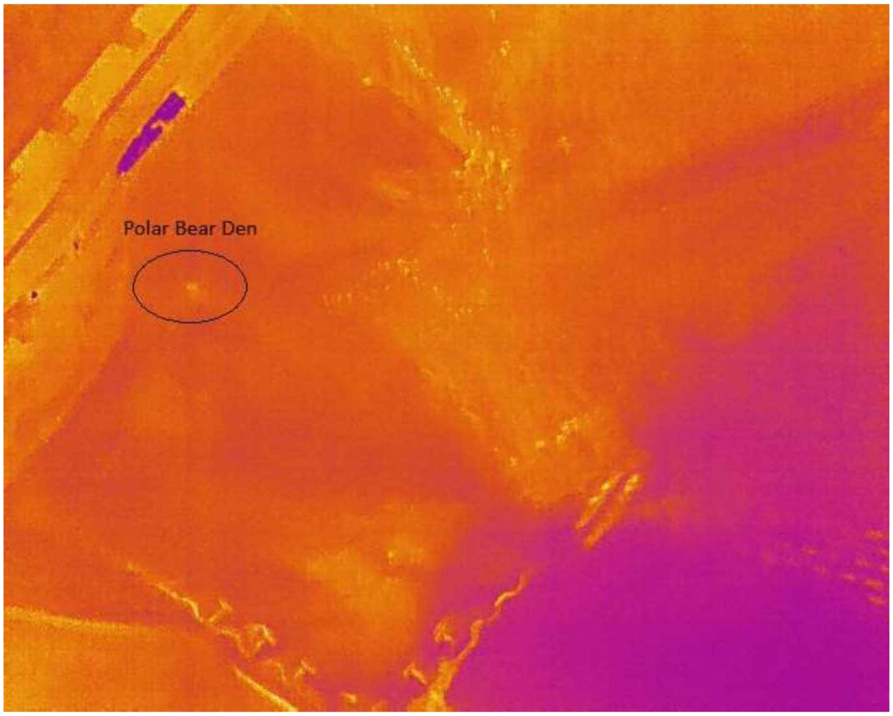


Figure 3.6. Occupied polar bear den observed by forward-looking infrared-equipped unmanned aircraft system from 50 m above the den in the North Slope Oilfields of Alaska (USA).

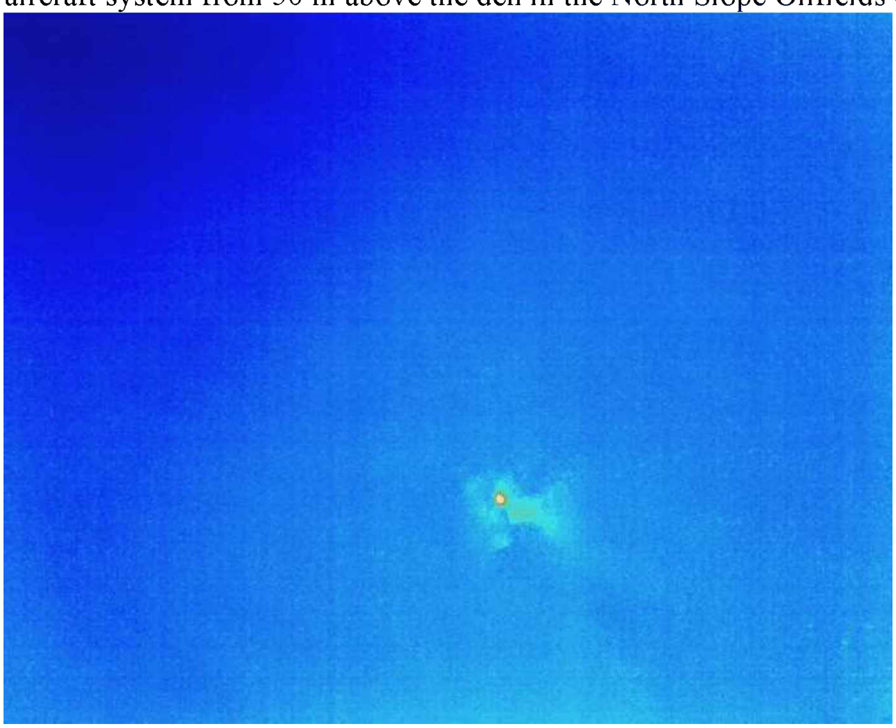


Figure 3.7. Image depicting the hot spot from entrance to an occupied grizzly bear den after disturbance from trained scent dog, observed by forward-looking infrared-equipped unmanned aircraft system from 30 m above the den in the North Slope oilfields of Alaska (USA).

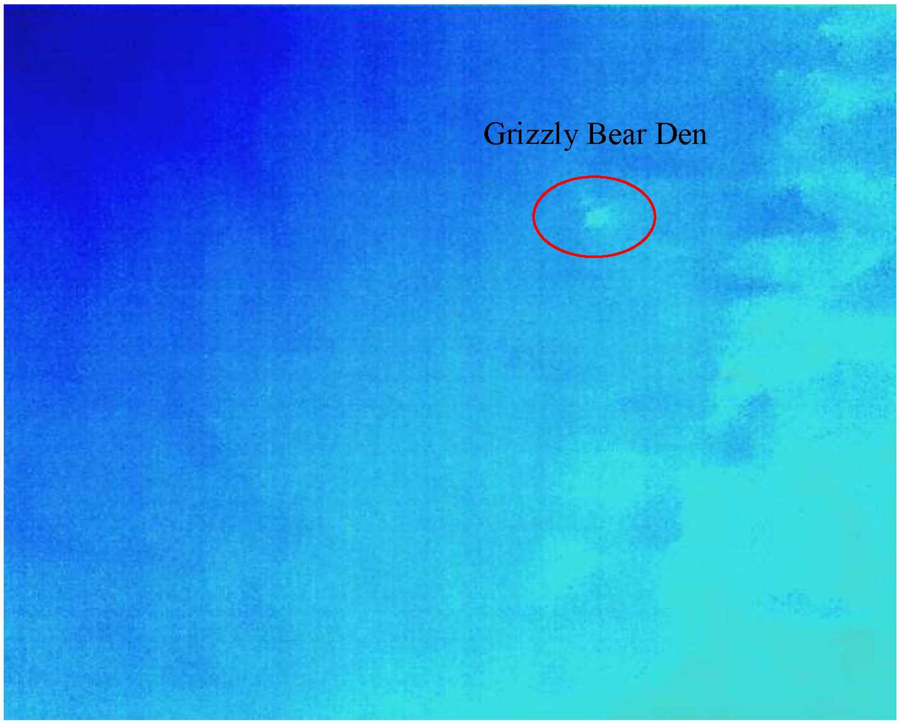


Figure 3.8. Image depicting the hot spot from entrance to an occupied grizzly bear den before disturbance from trained scent dog, observed by forward-looking infrared-equipped unmanned aircraft system from 30 m above the den in the North Slope oilfields of Alaska (USA).

3.10 Tables

Table 3.1. A comparison of means with standard deviation (SD) for artificial den dimensions, wall thickness (cm), and temperature characteristics (°C) of den interior, snow surface above the den, and ambient snow surface near the den, as well as predictor variables: air temperature (°C), wind speed (kph), and presence or absence of solar radiation and precipitation during the forward-looking infrared-based bear den detection study period in the North Slope oilfields of Alaska (USA).

		Polar Bear	**Grizzly Bear**
Den Dimensions (cm)	Depth	136.7 (SD 40.9)	94.3 (SD 21.2)
	Width	152.7 (SD 45.5)	126 (SD 41.2)
	Height	94.2 (SD 41.8)	86.7 (SD 23.6)
Den Wall Thickness (cm)	Mean	30.9 (SD 16.7)	51.6 (SD 45.8)
	Minimum	1	15
	Maximum	57	150
Temperature °C	Den Interior	-2.5 (SD 1.9)	-4.4 (SD 4.5)
	Den Surface	-10.1 (SD 6.9)	-11.9 (SD 8.4)
	Snow Surface	-18.1 (SD 8.3)	-18.1 (SD 8.3)
Air Temperature °C	Mean	-18.3 (SD 7.7)	-18.3 (SD 7.7)
	Maximum	-9	
	Minimum	-29	
Solar Radiation	Present	9	
	Absent	32	
Wind Speed (kph)	Mean	25.9 (SD 8.8)	
	Maximum	36.6	
	Minimum	5.6	
Precipitation	Present	20	
	Absent	21	

Table 3.2. Number of forward-looking infrared images of artificial dens included in analysis with median and interquartile range (IQR) pixel count of hot spot from the vertical and horizontal perspective at 20, 50, and 100 m distance, and difference between percent expected and percent actual hot spot pixel count decline at each increase in distance.

Artificial Polar Bear Dens						
	20 m		50 m		100 m	
	v	h	v	h	v	h
n	28	28	27	31	26	21
Median Hot Spot Pixel	248	78	170	36	100	15
IQR	195 – 560	54 – 132	93 – 351	12 – 55	56 – 156	8 - 33
Hot Spot Pixel Decline	-	-	+29%	+6%	+9%	-8%
Artificial Grizzly Bear Dens						
n	17	25	18	28	17	25
Median Hot Spot Pixel	160	29	101	17	51	8
IQR	122 – 246	20 – 48	51 – 197	10 – 32	25 – 130	8 – 22
Hot Spot Pixel Decline	-	-	+23%	+19%	0%	-3%

Table 3.3. Logistic regression model estimates of strength of influence (exponential beta coefficient, *Exp(B)*) of ambient weather predictor variables on odds of detection (odds of outcome "detection" instead of reference "non-detection") in forward-looking infrared images (*n* = 291) of artificial grizzly bear and polar bear dens observed from the vertical and horizontal perspective.

			Coefficients		95% CI	
Species	*Perspective*	*Variable*	*p-value*	*Exp (B)*	*Lower*	*Upper*
Grizzly Bear (*n*=130)	Horizontal (*n*=78)	Constant	0.03	0.00		
		Air Temperature	0.05	0.92	0.85	1.00
		Wind	0.08	1.18	0.98	1.42
		Precipitation[a]	0.47	3.51	0.12	105.40
		Solar[a]	(insufficient sample variation)			
	Vertical (*n*=52)	Constant	0.47	0.37		
		Air Temperature	0.77	0.99	0.91	1.07
		Wind	0.17	1.05	0.98	1.13
		Precipitation[a]	0.68	0.66	0.21	11.00
		Solar[a]	0.43	0.45	0.30	16.76
Polar Bear (*n*=161)	Horizontal (*n*=80)	Constant	0.79	0.64		
		Air Temperature	0.01	0.90	0.84	0.97
		Wind	0.53	0.97	0.86	1.08
		Precipitation[a]	0.06	0.10	0.01	1.05
		Solar[a]	0.88	0.89	0.18	4.32
	Vertical (*n*=81)	Constant	0.93	1.10		
		Air Temperature	0.00	0.88	0.82	0.95
		Wind	0.10	0.95	0.90	1.01
		Precipitation[a]	0.03	0.18	0.04	0.87
		Solar[a]	0.05	0.23	0.05	1.01

[a]Categorical variables (odds of detection outcome instead of non-detection with one category change: presence instead of absence of precipitation or solar).

3.11 Appendix A. List of weather conditions recorded at each sampling period.

Date	Site	Solar	Air Temperature	Snow Temperature	Humidity	Barometric Pressure	Dew Point	Temperature Dew Point	Wind	Gust	Precipitation	Clouds	Visibility
12/20/2016	KIC	No	-18.0	-17.0	85%	29.3	-20.0	-2.0	20.3	25.6	No	Med	16.0
12/20/2016	KIC	No	-18.0	-17.0	85%	29.3	-20.0	-2.0	20.3	25.6	No	Med	16.0
12/20/2016	DS2M	Yes	-21.0	-20.0	84%	29.2	-23.0	-2.0	25.8	25.6	No	Med	16.0
1/10/2017	KIC	Yes	-13.0	-11.1	79%	30.0	-15.0	-2.0	22.1	40.0	No	None	16.0
1/10/2017	KIC	Yes	-13.0	-11.1	79%	30.0	-15.0	-2.0	22.1	40.0	No	None	16.0
1/10/2017	KIC	Yes	-13.0	-11.1	79%	30.0	-15.0	-2.0	22.1	40.0	No	None	16.0
1/11/2017	DS2M	No	-11.0	-10.0	9%	30.0	-12.0	-1.0	35.0	36.8	Yes	Thick	3.2
1/11/2017	KIC	No	-11.0	-10.0	92%	30.0	-12.0	-1.0	35.0	36.8	Yes	Thick	3.2
1/11/2017	DS2M	No	-11.0	-10.0	92%	30.0	-12.0	-1.0	35.0	36.8	Yes	Thick	3.2
2/14/2017	DS2M	No	-29.0	-27.5	48%	29.6	-37.0	-8.0	11.7	15.0	No	Med	9.6
2/14/2017	DS2M	No	-29.0	-27.5	48%	29.6	-37.0	-8.0	11.7	15.0	No	Med	9.6
2/14/2017	DS2M	No	-29.0	-27.5	48%	29.6	-37.0	-8.0	11.7	15.0	No	Med	12.8
2/14/2017	KIC	Yes	-25.0	-23.8	64%	29.5	-30.0	-5.0	10.9	12.6	No	None	16.0
2/14/2017	KIC	Yes	-25.0	-23.8	64%	29.5	-30.0	-5.0	10.9	12.6	No	None	16.0
2/16/2017	KIC	No	-22.0	-21.0	65%	29.5	-27.0	-5.0	5.6	11.2	Yes	Med	6.4
3/6/2017	KIC	No	-27.0	-29.5	76%	30.5	-30.0	-3.0	31.4	38.4	Yes	Med	4.8
3/6/2017	KIC	No	-28.0	-29.5	76%	30.5	-30.0	-2.0	31.4	38.4	Yes	Med	4.8
3/6/2017	KIC	No	-28.0	-29.5	76%	30.5	-30.0	-2.0	29.4	38.4	Yes	Med	4.8
3/6/2017	KIC	No	-28.0	-29.5	76%	30.5	-31.0	-3.0	31.4	38.4	Yes	Med	11.2
3/6/2017	KIC	No	-28.0	-29.5	76%	30.5	-31.0	-3.0	31.4	38.4	Yes	Med	11.2
3/6/2017	KIC	No	-28.0	-29.5	76%	30.5	-30.0	-2.0	29.4	38.4	Yes	Med	4.8
3/7/2017	KIC	No	-26.0	-27.7	77%	30.6	-29.0	-3.0	22.1	33.6	Yes	Med	11.2
3/7/2017	DS2M	No	-28.0	-28.6	76%	30.5	-31.0	-3.0	33.1	33.6	Yes	Med	4.8

3.11 Appendix A (continued). List of weather conditions recorded at each sampling period.

Date	Site	Solar	Air Temperature	Snow Temperature	Humidity	Barometric Pressure	Dew Point	Temperature Dew Point	Wind	Gust	Precipitation	Clouds	Visibility
3/7/2017	DS2M	No	-28.0	-28.6	76%	30.5	-31.0	-3.0	33.1	33.6	Yes	Med	4.8
3/7/2017	DS2M	No	-28.0	-28.6	76%	30.5	-31.0	-3.0	33.1	33.6	Yes	Med	4.8
3/7/2017	DS2M	No	-28.0	-28.6	76%	30.5	-31.0	-3.0	33.1	33.6	Yes	Med	4.8
3/9/2017	KIC	No	-12.0	-20.0	79%	30.5	-15.0	-3.0	35.0	44.8	Yes	Med	11.2
4/13/2017	KIC	No	-9.0	-7.5	93%	30.4	-10.0	-1.0	31.4	35.2	Yes	Med	4.8
4/13/2017	KIC	No	-9.0	-7.5	93%	30.4	-10.0	-1.0	31.4	35.2	Yes	Med	4.8
4/13/2017	KIC	No	-9.0	-7.5	100%	30.4	-10.0	-1.0	35.0	35.2	Yes	Med	4.8
4/13/2017	KIC	No	-13.0	-12.0	92%	30.4	-14.0	-1.0	12.8	20.5	Yes	Med	1.6
4/13/2017	KIC	No	-9.0	-7.5	93%	30.4	-9.0	0.0	33.1	35.2	Yes	Med	6.4
4/14/2017	KIC	No	-11.0	-11.0	92%	30.4	-13.0	-2.0	19.2	27.2	Yes	Med	2.4
4/14/2017	KIC	No	-11.0	-11.0	92%	30.4	-13.0	-2.0	19.2	27.2	Yes	Med	2.4
4/15/2017	KIC	No	-14.0	-15.5	85%	30.4	-16.0	-2.0	36.6	53.3	Yes	Med	1.6
4/15/2017	KIC	Yes	-13.0	-11.9	85%	30.5	-15.0	-2.0	24.0	36.8	Yes	None	4.8
4/15/2017	KIC	No	-12.0	-12.2	85%	30.4	-14.0	-2.0	33.6	44.8	Yes	Med	3.2
4/15/2017	KIC	No	-16.1	-12.1	87%	30.5	-16.1	0.0	29.3	40.3	Yes	None	0.8
4/16/2017	DS2M	No	-12.9	-13.3	85%	30.5	-18.0	-5.1	35.2	43.2	Yes	Med	6.4
4/16/2017	KIC	Yes	-10.0	-11.3	79%	30.6	-13.0	-3.0	22.7	36.5	Yes	None	11.2
4/16/2017	DS2M	No	-12.9	-13.3	85%	30.5	-18.0	-5.1	35.2	43.2	Yes	Med	6.4
4/16/2017	KIC	Yes	-10.0	-11.3	79%	30.6	-13.0	-3.0	22.7	36.5	Yes	None	11.2

CHAPTER 4: CONCLUSION

The grizzly bear sighting study corroborates the findings of other research conducted on the spatial-temporal patterns of food-conditioned and natural-food bears in other parts of the world (Craighead and Craighead 1971, Milke 1977, Herrero 1985, Mattson et al. 1992, Wilson et al. 2005, Mazur et al. 2007, 2010, Bentzen et al. 2014, Johnson et al. 2015, Morehouse and Boyce 2017, Laufenberg et al. 2018). Food-conditioned bears were seen more frequently close to sources of anthropogenic food waste, and became concentrated when food waste disposal was restricted to a confined area, and they are more likely to be killed by humans in defense of life and property as a result of their lack of wariness toward human-occupied space. Natural-food bears were more likely to be seen around areas in which bear habitat intersects with human infrastructure, such as roads and facilities that traverse riparian zones or wildlife travel corridors. This study is unique in that it establishes that these principles of bear behavior also extend to the arctic regions, and it suggests that systematically collected observational data can be successfully used to map regions of bear spatial-temporal use and human-bear interactions to observe long-term trends and to make real-time management decisions. A similar kind of reporting system to the GBSHR could be used in other places that experience conflicts between humans and bear species. This reporting system could be used by trained professionals, or it could be more of a "citizen science" type of reporting system; for example, visitors to a national or state park could be instructed to report all bear sightings by logging a GPS location and time of sighting using a paper report form or perhaps a smartphone app. The key to a reporting system of this nature would be to eliminate each reporter's interpretation of bear behavior and focus on the descriptive elements of each sighting, and to make it relatively simple to report.

Finally, this grizzly bear sighting study reinforces the necessity for humans in their future activities in bear country to secure their food waste from bears. Previous research on the process by which bears become food conditioned indicates that it is largely dependent on the foraging behavior of the mother bear during the time in which she is rearing her cubs. If the mother bear is feeding on food waste, the cubs will learn this foraging behavior and will always have the capacity to exhibit a food-conditioned foraging strategy (Mazur and Seher 2007). This implies that if food waste is kept secure from bear access, local bears will never learn a food-conditioned foraging strategy, and negative human-bear interactions will be significantly reduced. Also implied is that if a bear does become food conditioned, especially a breeding age female, and if it is not possible to secure food waste attractants from bear access, managers should determine whether that bear should be removed before she is able to reproduce and pass on a culture of food-conditioned bear foraging strategy to her offspring. The oilfield grizzly bears that are removed by management are food-conditioned bears that have lost their natural wariness towards humans and actively seek food waste in and around human-occupied space. These bears are all related and can be traced back to several matriarch females that became food conditioned and taught this foraging strategy to their progeny, initiating a culture of behavior that has been shown to foster negative human-bear interactions and require a great deal of time and resources from management and local security personnel (Richard T. Shideler, unpublished data, Alaska Department of Fish and Game [ADF&G]).

Human activity can disturb grizzly bear and polar bear dens in the Arctic, and increased human activity in bear denning habitat will likely lead to an increased frequency of den disturbance if mitigating techniques are not employed to prevent it. The application of forward-looking infrared (FLIR) techniques for both grizzly bear and polar bear den detection has been demonstrated from the ground with hand-held cameras, from manned aerial platforms, and now through this study, which has shown that an unmanned aircraft system (UAS) has the potential to capture FLIR imagery of occupied bear dens in a safe and non-invasive way. The greatest advantages to a UAS-FLIR survey are as follows:

1) The UAS can achieve a vertical perspective of the den hot spot; the vertical perspective produces better quality detections than the horizontal perspective.
2) The UAS can hover at much lower distances ($\leq$ 100 m) than a manned aerial vehicle without causing disturbance to the bear in the den. An observation from a lower distance reduces the amount of interference that precipitation may have on a FLIR system's ability to detect heat differentials in the snow surface. At distances $\leq$ 100 m, our model indicated that colder air temperatures, calm wind conditions (< 15 kph), thinner den snow walls, and the absence of precipitation and solar radiation are the best predictors of odds of den detection, indicating that UAS-FLIR-based den detection surveys should take place in cold, dry conditions, during calm wind conditions, early in the winter season, during hours of darkness or civil twilight.
3) Unmanned aircraft systems are relatively inexpensive and require minimal training and expertise to operate compared with manned aerial platforms. The added advantage is that UASs are also much safer, in that the risk to human life is almost non-existent when operating a UAS as compared with manned vehicles.

The greatest disadvantages to a UAS-FLIR survey are (1) the physical limitations of current UASs, and (2) the current Federal Aviation Administration (FAA) restrictions on UAS operation mandate that the Pilot-in-Command is not permitted to fly above 122 m above ground level, in hours of total darkness, or beyond line of sight. In sub-zero temperatures, our UAS reached a maximum flight time of 12 to 15 minutes before the unit entered a “battery fail safe” mode and automatically initiated a landing procedure. More recent UASs are achieving 20 to 30 minutes in the cold, but it is not uncommon for temperatures to drop below -30°C in the North Slope oilfield area, and unless UASs are substantially improved for arctic conditions, their batteries will not perform well in very cold air temperatures when conditions are best for UAS-FLIR bear den detection. The UAS was difficult to operate safely and effectively in wind speeds exceeding 30 kph, even in automated flight modes. Future UASs will likely be able to overcome this limitation through improved design. Our UAS model was unable to operate safely during periods of high precipitation, which is a limitation that current systems have already overcome. These restrictions mean that high-altitude surveys, from which a greater swath of habitat could be surveyed, are forbidden, and that only a limited horizontal distance (< 1 km) from the Pilot-in-Command can be covered. Operation during nighttime hours may yield better detections. Unless exemptions are made to current regulations, manned aerial vehicles are clearly more practical for longer and more remote surveys. It is also possible that the noise produced from UAS propellers may cause a physiological response in the bears within the den, especially if the UAS is hovering at low altitude. This is a consideration for future research.

Forward-looking infrared imagery is currently the only technology that has demonstrated the ability to detect bear dens in the Arctic, and optimal uses are becoming better understood through repeated and more extensive testing and evaluation. With our robust sample size, known artificial bear den characteristics, fine-scale weather measurements, and modern post-processing software, a reliable UAS-FLIR-based den detection technique is still dependent on expert opinion, using visual elements of interpretation to classify imagery. It is possible that modern techniques in image recognition algorithms may be capable of reducing a large number of FLIR images to a subset of true positives and false positives, but we expect that it will be difficult for an algorithm to distinguish between these two classifications consistently due to the influence of weather and the variation in bear den morphology. The classification of a false negative is likely not possible to discern using an image recognition algorithm, unless other parameters are included in the classification, such as a known den location.

Our study indicates that UAS-FLIR should not be relied on to consistently detect grizzly bear dens, but the use of UAS-FLIR shows potential under ideal conditions to image the heat escaping from the den entrance location. One should expect UAS-FLIR to be more effective at locating grizzly bear dens on the North Slope than in more southerly regions because there are no trees or over-story to interfere with detection north of the Brooks Range in Alaska, and because den habitat on the North Slope has relatively uniform topography. These conditions are different from the more mountainous regions of North America, where grizzly bears establish their dens into the steep slopes of mountainsides. Artificial grizzly bear den #3 was the only den that we constructed in the style of a grizzly bear living in mountainous terrain: it was excavated into a 30° slope that extended roughly 30 m up out of a lake. This den was very difficult to observe throughout the winter season and impossible to observe after the snow wall reached a thickness of 125 cm over the den entrance. Grizzly bears that den in areas that can accumulate heavy snow loads, such as the foothills of the Brooks Range, may be harder to find than those established in the tundra of the coastal plain. Hence, multiple techniques may need to be employed to detect grizzly bear dens in timbered, mountainous terrain.

Our study indicates that UAS-FLIR shows potential for detecting polar bear dens on the North Slope, and we anticipate that advancements in technology combined with exemptions to FAA regulations will enhance the efficacy of this technique. It is unclear whether UAS-FLIR could be used in polar bear den habitat in other parts of the world, such as Svalbard, Norway, or Wrangel Island, Russia, areas where polar bears are establishing dens within snowdrifts associated with mountainous terrain. Considering that it is thought that polar bears will dig upwards from within their dens to maintain a snow wall of 1–2 m, it is possible that additional snow coverage would not equate to greater den snow wall thickness (Craig J. Perham, USFWS, Personal Communication, 24 August 2017). We expect that the optimal conditions for artificial polar bear den detection would apply to occupied polar bear dens on the North Slope of Alaska as well as in the mountains of Svalbard, but this should be tested through observation.

For practical applications in which industry is required to locate and avoid bear dens prior to winter exploration and expansion activities, we recommend that UAS-FLIR surveys be coupled with a secondary method, such as repeat surveys or the application of trained scent dogs, to reduce the occurrence of false positives and, most importantly, false negatives (Shideler and Perham 2013, Shideler 2014). For research purposes, we recommend that occupied bear dens indicated by any method should also be confirmed by ground-based, snow-free verification surveys or camera trap systems to confirm that the location of the detection constitutes a true positive. Snow-free confirmation will allow researchers to further understand the success rate of these den detection techniques. We believe that this combined methodology, using UAS-FLIR and a secondary method, presents a promising tool for arctic bear den detection that will enhance worker safety and bear conservation on the North Slope oilfields of Alaska, with broad application throughout the arctic region.

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